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60-DAY MANNED TEST OF A REGENERATIVE LIFE SUPPORT SYSTEM WITH OXYGEN AND WATER RECOVERY

PART I
Engineering Test Results

DECEMBER 1968

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by

Advance Biotechnology and Power Department
McDonnell Douglas Astronautics Company – Western Division
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FOREWORD

A 60-day manned test of an advanced life support system in a Space Cabin Simulator (SCS) was completed on April 19, 1968. This test was conducted by the Advance Biotechnology and Power Department of the McDonnell Douglas Astronautics Company--Western Division (MDAC-WD), Santa Monica, California, under Contract NASw-1612. This project was completed for Walton L. Jones, M.D., Director of the Biotechnology and Human Research Division and for J. N. Pecoraro, Chief of the Biotechnology Branch, under the direction of A. L. Ingelfinger, all from the Office of Advanced Research and Technology, Headquarters, the National Aeronautics and Space Administration, Washington, D. C.

M. S. Bonura was the Principal Investigator for McDonnell Douglas. Preparation for the 60-day test was sponsored by capital expense procurement AFE No. 1410-372 and included the purchase of specialized life support equipment such as the Sabatier hydrogenation unit, the water electrolysis unit, major components of the water recovery and the carbon dioxide concentrator subsystems, and laboratory components such as a gas chromatograph. This preparation also included modifications and additions to the Space Cabin Simulator for safety purposes. Preliminary life support equipment development and tests, modifications to the SCS related facilities, and substantial personnel support during the 5-day manned shakedown test and the 60-day manned test were accomplished under the sponsorship of the MDAC-WD Independent Research and Development Program.

This report was prepared under the direction of M. S. Bonura and W. S. Clark, with the assistance of:

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This volume contains the engineering test results obtained from the 60-day manned test. The complete test report consists of the following parts:

CR-98500 - 60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery, Part I - Engineering Test Results

CR-98501 - 60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery, Part II - Aerospace Medicine and Man-Machine Test Results

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Section 1

SUMMARY

A 60-day manned test of a closed regenerative life-support system was conducted in a Space Cabin Simulator at the McDonnell Douglas Astronautics Company-Western Division (MDAC-WD) Biotechnology Laboratory in Santa Monica, California.

The life-support system under test featured potable water recovery from urine and humidity condensate and oxygen recovery from carbon dioxide removed from the cabin atmosphere by a regenerable concentrator using a molecular sieve as an adsorber. Other important elements of the environmental control and life-support system included a catalytic oxidizer for removal of trace contaminants, a two-gas atmosphere control, thermal and humidity control subsystems, and a waste management subsystem.

The Space Cabin Simulator is a double-walled vessel normally operated with the annular pressure below the internal pressure to ensure leakage from inside to outside. Four inches of thermal insulation are applied to the outside of the chamber. Access is provided through a 150-cu-ft airlock, and two smaller pass-through ports are used for transfer of equipment, specimens, mail, etc. During normal operation, an atmospheric pressure of 362 mm Hg abs was maintained, with an oxygen partial pressure of 160 mm Hg.

In addition to the primary components of the environmental control and life-support system, a number of secondary evaluations were conducted on equipment furnished by various Government agencies or manufacturers. This equipment is listed in Table 1. Detailed descriptions and results of evaluations of this equipment are furnished in Section 4, Test Results.

The test subjects who comprised the SCS crew were four young healthy male college students. At least five persons, including engineers, technicians, and a licensed physician, were continuously stationed outside the SCS to provide facility operation, consultation, and test safety. The majority of the life-support subsystems were installed in the SCS prior to testing, and throughout the 60-day manned test were monitored, operated, and maintained by the test crew under conditions comparable to those which would be encountered by an earth-orbiting laboratory operating on a 1-year mission with 60- to 90-day resupply periods.

Test observations and results from the 60-day manned SCS study are reported in two parts. This document, Part I, covers engineering test procedures and results. Part II describes aerospace medical factors and man-machine monitoring and testing procedures employed to evaluate the health of the crew, crew interpersonal dynamics, and man-machine/man-environmental integration (Reference 1).

Table 1

PIGGY-BACK EVALUATIONS DURING THE 60-DAY MANNED TEST

ITEM	MANUFACTURER	AGENCY	EVALUATION
Advanced Four-Gas Mass Spectrometer Sensor	Perkin-Elmer	NASA/LRC	Feasibility was demonstrated. Frequent calibration required.
Zero-g Water Condenser/ Separator	Lockheed	NASA/LRC	Effective operation. Some sub-assembly reliability problems.
Waste-Management Commode	General Electric	USAF/AMRL	Very good operation. Crew acceptance was very good.
Astrovac Personal Hygiene Unit	Republic-Fairchild Hiller	---	Unit should be effective for zero-g body bathing
Silver-Ion Generator	Garrett Corporation	---	Appeared to have contributed to longer filter life. Further testing required.
Perceptual Motor Performance Monitor	Biotechnology, Inc.	NASA/OART	Provided useful information on crew performance.
Multichannel Medical Monitoring System	Philco-Ford	NASA/ERC	Subject response to dry electrodes excellent. Imposed test conditions reduced unit efficiency.
Beta Fabric for Clothing and Equipment Covers	B. Welson Co.	NASA/MSC	Successfully met test requirements. Test revealed that a close-fitting, stretch, two-piece constant wear garment is most desirable.
PBI Fabric for Clothing and Equipment Covers	Celanese Corp.	USAF/WPAFB	
Aerosol Particle Counters	Block Eng., MSA	NASA/ERC	Very useful in determining purity of SCS atmosphere.

1.1 LIFE-SUPPORT SYSTEM OPERATION

The major portion of the life-support system was installed within the simulator and was monitored, maintained, and repaired when necessary by the inside crew. Space limitations dictated the external location of the atmospheric supply and control console and the electrolysis unit of the oxygen recovery subsystem. The reliability of the equipment was generally very good, and, because the test crew was capable of making all necessary repairs and adjustments, no one was required to enter or leave the simulator during the entire test. The history of operation of the life-support systems during the test is shown in Figure 1. A summation of repair and maintenance items is shown in Table 2. The table lists 47 different maintenance and repair tasks. Twenty of these are repeats, with a total of 27 different types of malfunctions. Many of the malfunctions would not have occurred on fully developed and qualified equipment. The maintenance information obtained from this test will be used to design equipment for better maintainability.

Operation of the environmental control subsystems was characterized by a generally warm, dry atmosphere. Fluctuations in total pressure, oxygen partial pressure, and relative humidity were very small. Trace contaminants were efficiently removed by the toxin burner, carbon dioxide concentrator, and charcoal adsorbent beds, and the atmosphere was relatively free of odors or aerosol particles. Table 3 summarizes the environmental parameters encountered during the test.

The potable water recovery subsystem produced water suitable for crew consumption throughout the run except for about 3 days following day 39. At this time, a positive bacteria count was obtained from a sample of water from the storage tank ready for consumption. Subsequent analysis indicated this was probably because of a contaminated sample port, but 3 days were required to perform the analyses necessary to requalify the water for consumption. During this time, all four test subjects consumed water provided from the external backup system. During the balance of the test, two crewmen consumed recovery water, and the other two who served as controls, used water from the external supply.

The operation of the water recovery subsystem is summarized in Table 4. For comparison, nominal design values are also tabulated. The major differences between the design values and the test results are the significant decrease in the ratio of urine to humidity condensate and the recorded value of crew consumption rate. It is believed that the decrease in urine production was caused by the warm, dry atmosphere of the SCS, which increased latent losses at the expense of urine production, as is typical in "desert" environments. The low value of crew consumption appears to be a result of incomplete records and/or inaccurate measurements. These data depended upon manual operations by all crew members, and review of the data indicates the questionable accuracy of these records.

Operation of the oxygen recovery subsystem is summarized in Table 5. Consumption of oxygen and production of carbon dioxide are near design values. Water produced by the Sabatier reactor is also near the design value considering that the average of the data includes a number of days when the unit was shut

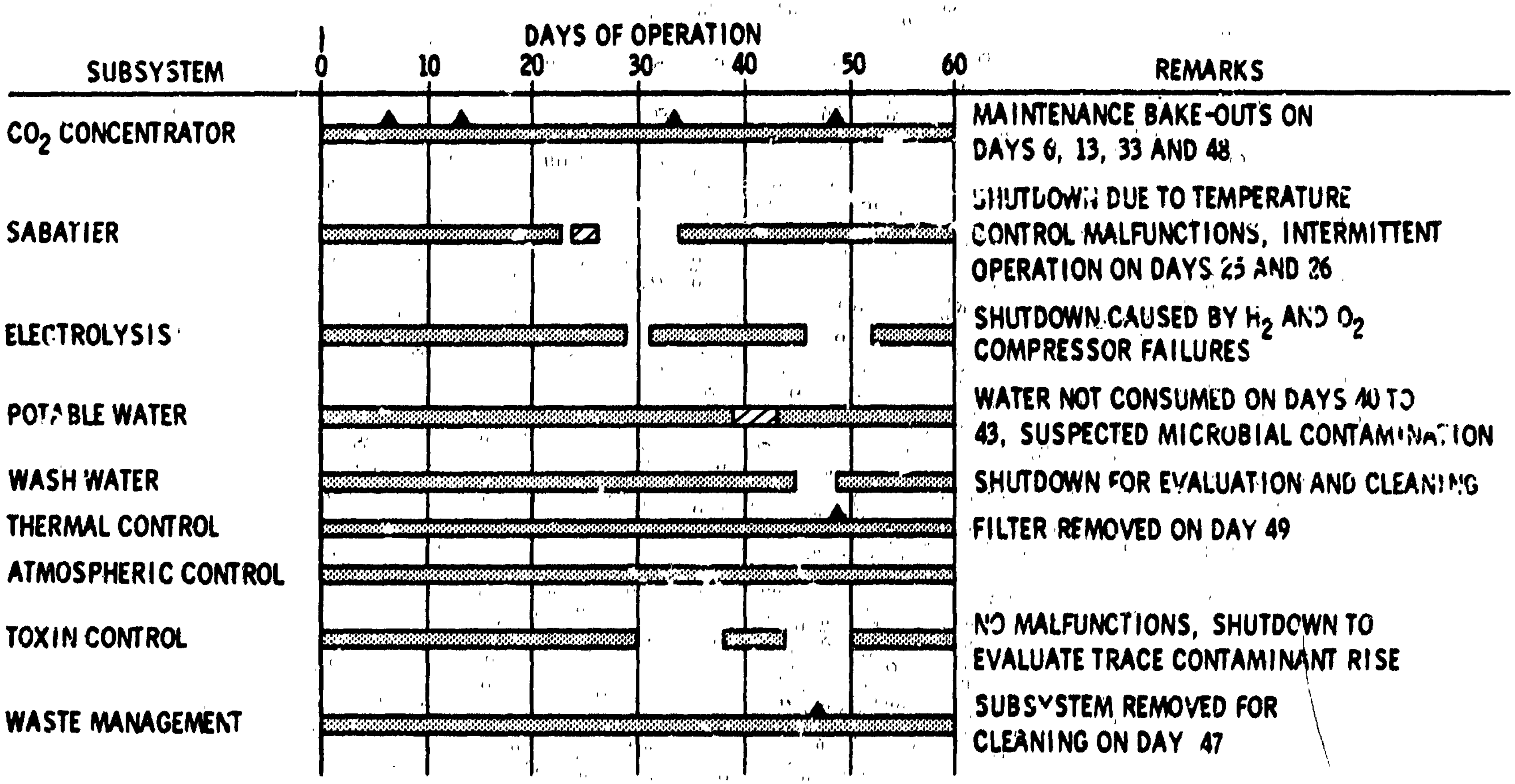

Figure 1. Life Support Subsystems Operation

Table 2

SUMMARY OF UNSCHEDULED MAINTENANCE AND REPAIRS

Subsystem	Module	Failure	Number of Times	
Oxygen Recovery	Electrolysis	Diaphragm Compressor	6	
		Gas leak	1	
		Rectifier shorted	1	
		Air filter plugged with dust	1	
	Sabatier reactor	Temperature controller	5	
		Flowmeter	1	
	CO_2 Concentrator	Time-delay relay	1	
		Cam timer switch	1	
		Vacuum pump clogged with molecular sieve dust	1	
		Valve actuator adjustment	1	
		Subtotal		19
Water Recovery	Wash water	Hose malfunction	1	
		Pump failure	3	
	Potable water	Leakage	1	
		Line blockage	2	
		Liquid-level switches	1	
		Silver-ion generator*	1	
	Zero-G water Separator	Plugged sump screens	3	
		ΔP switch	2	
		Condenser*	1	
		Subtotal		15
Waste Management	Fecal collector	Leak in toilet paper collector to vacuum	1	
		Fecal collector full	1	
		Subtotal		2
Thermal Control	Air filter	Plugged with dust	1	
		Subtotal		1
Miscellaneous	Communications	TV malfunction	4	
		Intercom malfunction	2	
	Ergometer	Overheating	2	
	Lighting	Replace bulb	1	
	Astrovac bathing unit	Sponge head plugged	1	
		Subtotal		10
		TOTAL		47

*No failure. Removed for evaluation only.

Table 3

REPRESENTATIVE ENVIRONMENTAL DATA

	Low	Normal	High
Temperature, °F (Command Center)	74	78	82
Relative humidity, percent	28	30	36
Total pressure, mm Hg abs	356	362	368
Oxygen partial pressure, mm Hg	152	156	160
Carbon dioxide partial pressure, mm Hg	2.6	4.0	7.25
Carbon monoxide, ppm	10	15	35

Table 4

WATER RECOVERY SUBSYSTEM PERFORMANCE

	Design	Test Results	
	Nominal lb/Man Day	Actual lb/Man Day	Actual lb. Total
Urine produced	3.93	2.13	510
Urine solids	0.19	0.105	24.9
Wick used	--	0.0415	10.0
Humidity condensate	3.05*	3.825	919.6
Total water produced	6.81*	5.85	1403 6
Samples for analysis	--	0.57	136.9
Discarded-impure	--	1.77	425
Discarded-excess (due to consumption by 2 men only)	--	2.00	480
Added from backup system	--	2.105	505
Consumed by crew	6.33*	3.805	913

*Includes 0.35 lb/man-day allowance for evaporated or lost in food preparation.

Table 5

OXYGEN RECOVERY SUBSYSTEM PERFORMANCE

	Design Nominal lb/man day*	Test Results Actual lb/man day	Total lb
Oxygen consumed	2.014*	2.04	489
Carbon Dioxide Produced	2.25	2.10	504
Water produced by Sabatier Reactor	1.023	1.231	296
Makeup water added	1.246	2.61	626
Hydrogen produced by Electrolysis	0.253	0.395	94.8
Oxygen produced by Electrolysis	2.014	3.44	827
Oxygen vented	0	1.486	358
Oxygen added from backup supply	0	0.083	20.0

*Includes 0.151 lb/man day for leakage makeup

down and no production occurred at all. However, the operating mode of the electrolysis unit was to produce enough hydrogen to process all the carbon dioxide produced. As a result, the makeup water requirement was excessive, and considerable excess oxygen was produced that had to be vented overboard. The nominal design values reflect a more efficient operating mode in which enough water is electrolyzed to furnish oxygen for the crew usage and the hydrogen production is not adequate to process all the carbon dioxide. Some unreacted carbon dioxide is then dumped overboard with the methane exhaust of the Sabatier reactor.

1.2 SUBSYSTEM OPERATING CHARACTERISTIC

In addition to the general operating characteristics of the oxygen recovery and water recovery subsystems summarized above, a general review of subsystem operation is presented in the following discussion.

1.2.1 Atmosphere Supply and Pressurization

The atmosphere supply and pressurization system included a Sabatier reactor, an electrolysis unit, and a two-gas control. Performance of the Sabatier reactor was, in general, very good. It operated 51 of the 60 days. Failure of the reactor temperature controller accounted for the down time. Manual temperature control was successfully used during the last 26 days of the test period after failure to provide a satisfactory replacement for the automatic control. Calculated carbon dioxide reaction efficiencies, based on outlet gas composition, were 90 to 93 percent. The catalyst showed no visible signs of deterioration upon test completion.

The electrolysis unit produced hydrogen and oxygen of acceptable purity. Repeated failures of both hydrogen and oxygen compressors resulted in 9 days of down time. This industrial unit will be replaced in the future with a more reliable on-board, flight-type unit.

The two-gas atmosphere control subsystem was used to supply the proper amounts of oxygen and nitrogen to the cabin as determined by the appropriate received sensor signals. A polarographic oxygen partial pressure sensor and a strain gage total pressure sensor were used for control, but their use was discontinued to evaluate the 4-gas mass spectrometer system as a controller. However, the output of the polarographic oxygen partial pressure sensor was checked against the reading of the paramagnetic analyzer for the duration of the test. The 60-day average oxygen partial pressure was 155 mm Hg, and of the average total pressure was 362 mm Hg.

The advanced 4-gas mass spectrometer was furnished by the NASA-Langley Research Center (NASA/LRC). The unit presents an analog signal on a 0-5 Vdc range proportional to a concentration of oxygen, nitrogen, carbon dioxide, and water vapor. After an initial qualification period, it was used to furnish the oxygen partial pressure signal to the two-gas controller for the remaining 46 days and the nitrogen partial pressure signal for the last 32 days of the test.

1.2.2 Water Management

The open-cycle air evaporation water recovery subsystem operated successfully for the full test period, producing potable water from urine and humidity condensate. The National Academy of Sciences/National Research Council (NAS/NRC) potability standards (Reference 2) were used to qualify the water as potable. The automatic pretreatment and post-treatment technique proved feasible. Data for an improved, simplified cyclic heat sterilization technique for the post-treatment unit was obtained.

The multifiltration wash water recovery subsystem operated for 56 of the 60 days of the test period. Dilution of the bactericide concentration (BAK) plus a possible filter failure caused a loss of microbial control and restricted the use of the system for 4 days while corrective action was taken. The charcoal and resin columns continued to remove the bulk of organic and inorganic materials for the entire test period, but there is a need to prolong microbial filter effectiveness for completely satisfactory performance.

The zero-g water condenser/separator was furnished by NASA/LRC and was installed as part of the potable water recovery subsystem. The unit operated 47 of the 60 days with minor maintenance involving the replacement of the hydrophilic sumps and a pressure switch. The 13 days of down time were a result of the investigation of a suspected condenser cooling-fluid leak. After installing a spare unit, the condenser/separator was put back into operation. No leakage was found in the original unit. The unit satisfactorily removed 100 percent of the condensed water, except when the water production rate exceeded the sump valve capacity for that particular opening, in which case the water level rose above the sump and was forced through the hydrophobic screen.

The silver-ion generator was installed in the potable water recovery subsystem to evaluate its effectiveness as an adjunct to microbial control. The unit was adjusted to add ionic silver to the water stream in a nominal concentration of 200 ppb. The generator was operated the first 21 days and the last 10 days of the test. The bacterial data immediately downstream of the generator demonstrated that the unit was effective in inhibiting bacterial growth, but growth was not completely inhibited further downstream.

1.2.3 Atmosphere Purification and Control

The atmosphere purification and control system included the carbon dioxide concentrator and toxin control subsystems. In addition, trace contaminants were removed by the charcoal adsorbent beds in the potable water recovery subsystem, by particulate filters in the thermal control subsystem, and by the silica gel and molecular sieve beds in the carbon dioxide concentrator. Further studies are required to determine the types and quantities of trace contaminants that can be removed by these beds.

The carbon dioxide concentrator operated throughout the test. Bakeout operations were carried out four times during the test to desorb accumulated water vapor from the molecular sieve beds and thereby restore their capacity for adsorption of carbon dioxide. Breakthrough curves obtained during the run indicate that the bed performance could be restored to initial values by performance of these bakeout cycles, which consisted of heating to 300°F and exposure to simulated space vacuum (less than 1 mm Hg abs) for about 1-1/2 hours.

The toxin control subsystem operated satisfactorily for the entire 60 days. The subsystem was deliberately shut down for one period of 8 days and one period of 6 days to evaluate the rate of carbon monoxide buildup. The 8-day period resulted in an increase from 13 ppm to 31 ppm, and the 6-day period resulted in an increase from 19 ppm to 35 ppm. In both instances, the carbon monoxide level returned rapidly to normal after the system was reactivated. Daily air samples were withdrawn from the cabin and analyzed for various organic and inorganic compounds. Levels of the more significant contaminants detected during the 60 days are given in Table 6.

An aerosol particle analyzer (APA) and membrane filter (MF) were supplied by the NASA Electronic Research Center (NASA/ERC). The MF data indicate that the average concentration of particles greater than 1 micron was 18.9 thousand per cubic foot, and the average concentration of for particles greater than about 0.6 microns was 46.8 thousand per cubic foot. These values are low and reflect the cleanliness of the cabin environment. The measured particle concentrations also indicated a gradual decline during the test period. The APA data indicated the same decrease in aerosol numbers over the test period as the MF data. Comparison of numbers of particles inside and outside the simulator further confirmed the cleanliness of the cabin environment.

1.2.4 Thermal and Humidity Control Subsystems

The thermal control subsystem operated satisfactorily during the test. The only maintenance performed was the removal of the inlet air filter because of

Table 6

ATMOSPHERIC CONTAMINANTS IN SPACE CABIN SIMULATOR

Contaminant	Maximum	Normal	Abort Alert* at 7 psia
CO (ppm)	35.0	17.0	100.0
CO_2 (mm Hg)	7.25	4.0	12.0
Hydrocarbons (ppm)	35.0	5.0	400.0
NH_3 (ppm)	17.4	6.3	100.0
Aldehydes (ppm)	0.89	0.34	20.0
SO_2 (ppm)	10.0	0.2	0.05
H_2S (ppm)	0.0	0.0	20.0
$(NO)_x$ (ppm NO_2)	0.7	0.11	10.0
O_3 (ppm)	0.0	0.0	0.2
Chlorine (ppm)	0.0	0.0	2.0
Cyanides (ppm)	0.0	0.0	20.0
Phosgene (ppm)	0.0	0.0	2.0

*NOTE: Allowable levels for maximum 8-hour exposure.

dust clogging after 49 days of operation. The humidity control subsystem was to be used as a backup to the open-cycle air evaporation water recovery subsystem, but was never required.

1.2.5 Waste Management Commode

The waste management commode was furnished by the USAF Aerospace Medical Research Laboratories (USAF/AMRL). The unit operated very satisfactorily for the entire test period. The fecal container was sized to accommodate four men for 30 days, so a separate toilet paper container was installed to extend its life. The unit required cleaning after 47 days and contained 11.5 lb of dried feces at that time. The total collection of dried fecal material for the 60 days was 14.2 lb.

1.3 CONCLUSIONS

The completion of the 60-day test provided information that will be useful in the development of future spacecraft life-support systems. The major conclusions that may be drawn from this test are as follows:

1. Regeneration of potable water from urine and humidity condensate is practical for space missions of extended duration. The open-loop air evaporator system is one means of providing this reclamation.
2. Regeneration of oxygen from carbon dioxide by the Sabatier reactor and water electrolysis is practical for missions of extended duration. The major problems encountered during the 60-day test with the subsystem can be solved or eliminated by replacing the industrial electrolysis unit with a more reliable on-board, flight-type unit.
3. The ability of the space cabin crew to perform unscheduled repair and maintenance tasks has been indicated by the performance of 47 operations, of 27 types, during the 60-day test.
4. Introduction of the open-loop air evaporation water recovery equipment was accompanied by an increase in ammonia concentration in the cabin, with a possible secondary production of oxides of nitrogen. However, the trace contaminant removal equipment was effective in preventing these and other toxic compounds from approaching alarm levels.

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Section 2
INTRODUCTION

This report contains the life-support system engineering test results from the 60-day manned test of the McDonnell Douglas Space Cabin Simulator (SCS). Subsystem descriptions, operational test procedures, complete facility description, and equipment checkout procedures are also included. The aerospace medicine and man-machine integration test results are reported in Reference 1.

The Space Cabin Simulator is a double-walled cylinder 12 ft in diameter and 40 ft long. The 4, 100-cu-ft chamber contains a 150-cu-ft airlock and two 18-in. diameter pass-through ports which are used for transferring test data, records, specimen containers, material samples, food, etc., into or out of the chamber. The chamber is normally operated at reduced atmospheric pressures to duplicate planned space cabin gas compositions, and the annular space between the inner and outer walls is evacuated slightly below cabin pressure to ensure that all leakage is outward to provide realistic testing of environmental control and life-support equipment. The chamber is insulated with 4 in. of thermal insulation to minimize heat loss. Figure 2 shows the general internal arrangement of the simulator, including major equipment items of the life-support system.

The primary objectives of the 60-day manned test were as follows:

- Perform a long-duration test of a life-support system simulating an earth-orbital mission having a duration of 1 to 2 years with resupply.
- Maintain acceptable water potability standards while operating an open-cycle wick evaporator water recovery subsystem.
- Evaluate an oxygen recovery subsystem including a Sabatier reactor and water electrolysis unit.
- Evaluate the ability of the crew to service, maintain, and repair on-board life-support subsystems.
- Determine microbial profiles of crew and equipment.
- Obtain realistic test results to upgrade environmental control and life-support equipment and to improve methods for future subsystem design and specification optimization.

A secondary objective of the 60-day test was the evaluation of various components and materials for life support and crew accommodation. The items to be evaluated were provided to McDonnell Douglas by various contractors and/or governmental agencies listed in Table 1.

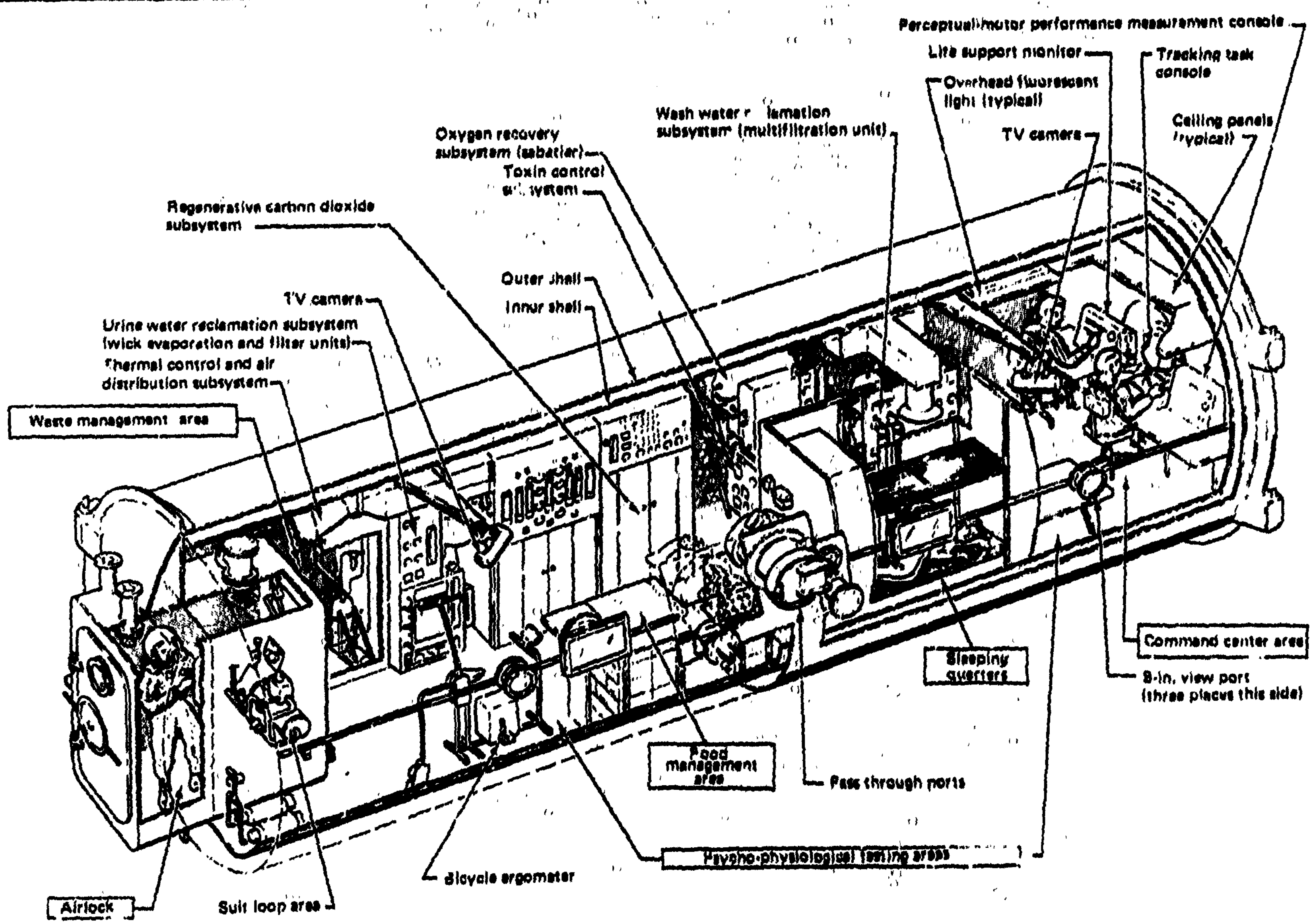


Figure .. Inside View of the Space Cabin Simulator

The functions of areospace medicine and man-machine integration during the 60-day test included a primary responsibility to support the test crew as required to meet the engineering objectives of the test. This included medical surveillance and monitoring, psychological evaluation, and habitability studies necessary to ensure the health and well-being of the crew. In addition, secondary medical and psychological studies were undertaken where possible without interference with the primary goal, and evaluation of several crew support items was undertaken to provide data for further tests. The complete descriptions and results of these efforts appear in Reference 1.

The 60-day test was conducted in the SCS, which had been modified to include an oxygen recovery subsystem and an improved water reclamation subsystem. The life-support equipment that was used in previous manned tests (Reference 3) was upgraded to improve its performance and reliability. The SCS atmosphere was maintained at 7 psia (362 mm Hg) total pressure, with an oxygen partial pressure of 3.1 psia (160 mm Hg) and a nitrogen diluent.

The SCS was manned by a crew of four, and at least five persons, including engineers, technicians, and a licensed physician, were on duty outside the SCS continuously to provide for test safety, consultation, and facility operation. Figure 3 shows the exterior of the SCS. Most of the subsystems required for life support were installed in the SCS, and the test crew was required to monitor, operate, and maintain them. The equipment provided support for a four-man crew under conditions comparable to those which would be encountered by an earth-orbiting laboratory operating on a 1-year mission with 60- to 90-day resupply periods. The SCS provided the means to study and develop engineering designs for operational, integrated spacecraft life-support systems; to investigate the effects of increasing the degree of closure of life-support cycles; and to evaluate the man-machine interactions that might occur. The test provided experimental data to upgrade computer programs, such as the G-189 generalized environmental control and life-support Fortran program, which are used to analyze and evaluate life-support systems.

Although valuable data on life-support equipment operation are presented in this report, it is considered important to evaluate this information in terms of its contribution to system integration rather than to the basic data on life-support requirements. The test was not structured to provide new data on human metabolic balances, for example, and the information presented should be used as a guide to system operation, but is not intended to contradict, or to extend, other sources of similar data.

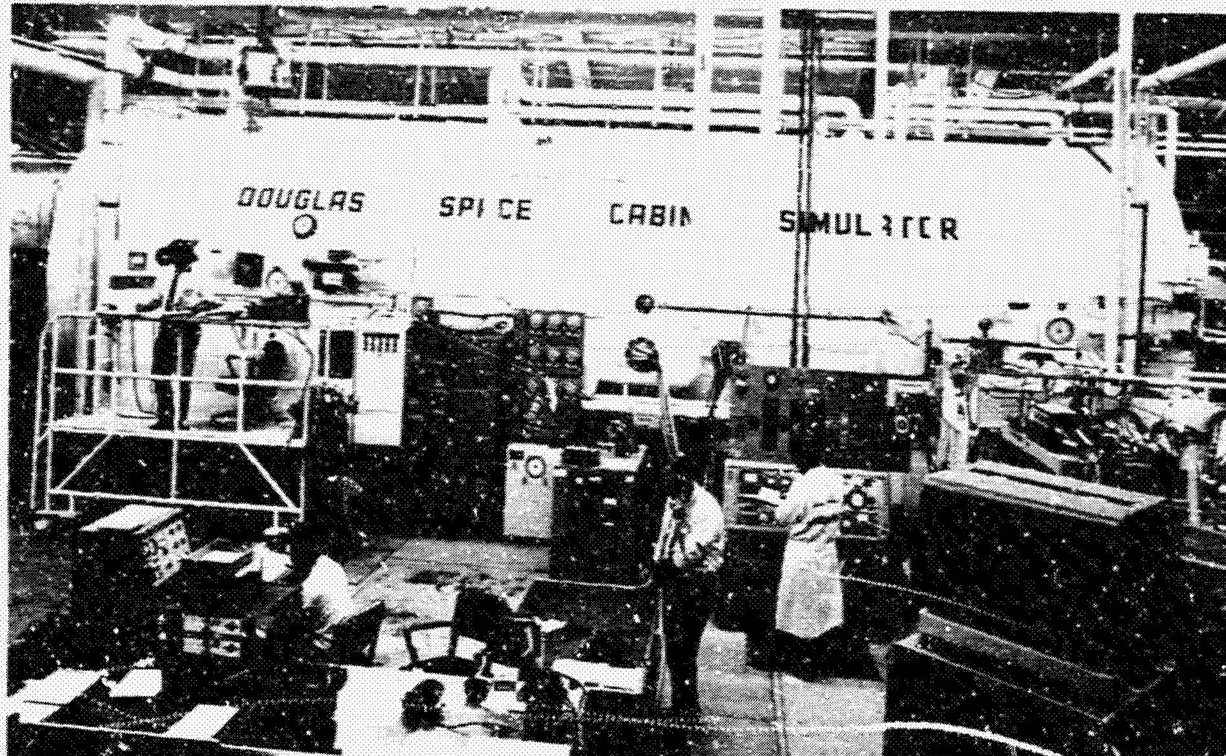


Figure 3. Space Cabin Simulator During Manned Test

Section 3

TEST PROCEDURES

The operational requirements and procedures that were used during the 60-day test are reviewed in this section. This description includes a definition of operating conditions, criteria, and requirements for the operating crew; the specification of test safety rules; the definition of emergency procedures; and a discussion of the requirements for pass-through operation.

3.1 OPERATING CONDITIONS AND CRITERIA

The nominal values for atmospheric pressure, composition, temperature, and humidity, as shown in Table 7, were established in accordance with physiological and safety requirements.

Table 7

NOMINAL PRESSURE, COMPOSITION, AND TEMPERATURE OF TEST ATMOSPHERE

Total pressure	357 to 367 mm Hg
Oxygen partial pressure	155 to 160 mm Hg
Cabin temperatures	70° to 80°F
Relative humidity	30 to 70%
Carbon dioxide partial pressure	3 to 6 mm Hg

The physiological criteria include the comfort-zone data (Reference 4) that relate ambient temperature and relative humidity, and the alveolar pressures required to prevent hypoxia. The alveolar oxygen pressure (the oxygen partial pressure in the lung) must be maintained above a specified minimum to ensure proper oxygen transfer to the blood during breathing. The alveolar pressure does not depend on atmospheric oxygen partial pressure alone, but is also a function of the total atmospheric pressure, as shown in Figure 4. Proper alveolar oxygen pressure is maintained at any combination of the atmospheric oxygen partial pressure and the total atmospheric pressure that falls on the cross-hatched region between the alveolar oxygen pressure curves in Figure 4. The information in this figure was developed from Reference 5, 6, and 7.

The safety criterion discourages the use of oxygen partial pressure above 160 mm Hg, which is the normal sea-level value. The region meeting this interior is shown in Figure 4 as the lightly shaded area below 160 mm Hg atmospheric oxygen partial pressure. This limit of 160 mm Hg (3.1 psia) oxygen partial pressure was strictly observed throughout the test.

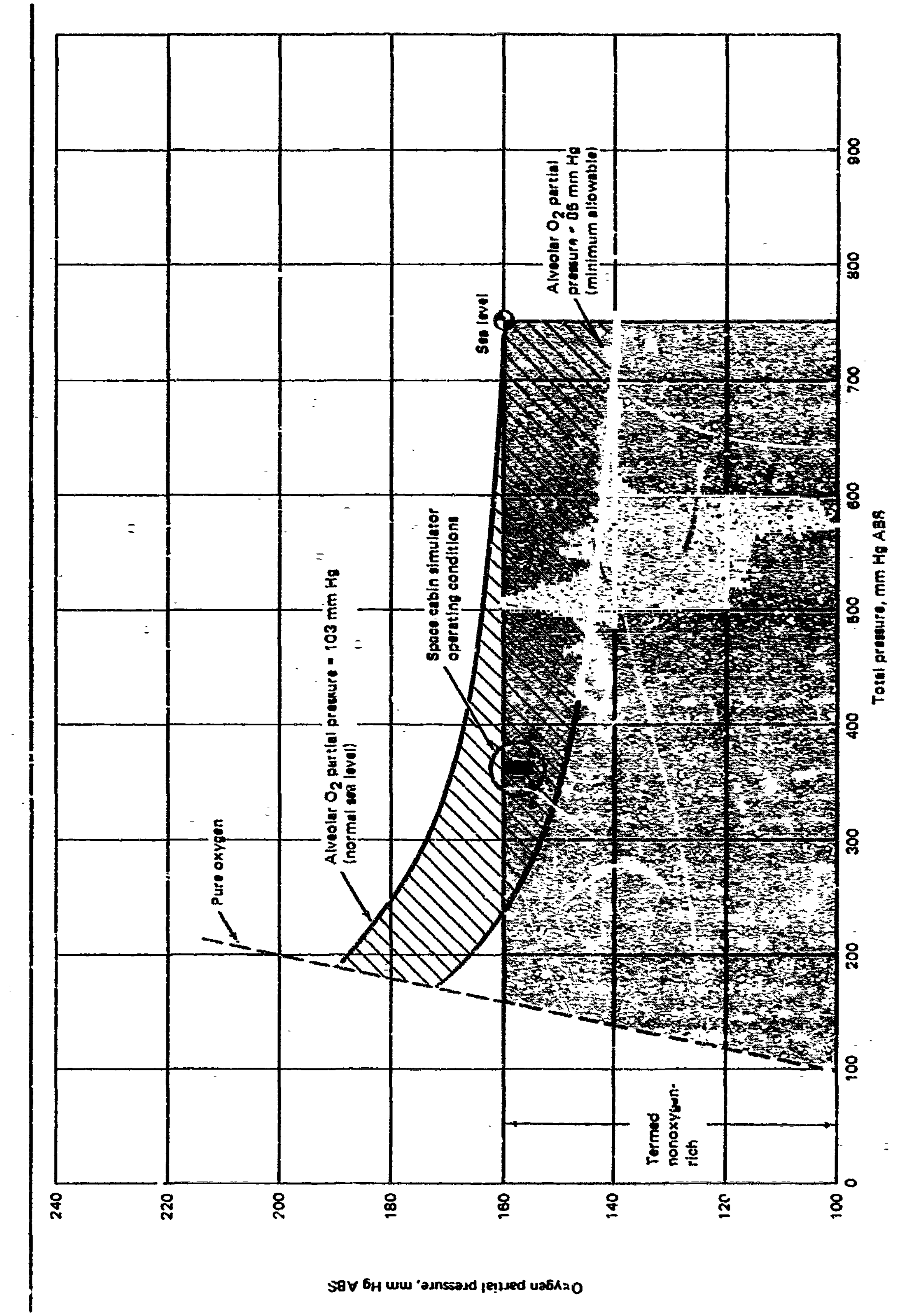


Figure 4. Oxygen Partial Pressure vs Total Pressure

As shown in Figure 4, the observance of both the criteria for proper alveolar oxygen pressure and a nonoxygen-rich atmosphere requires that a diluent be added to increase the total atmospheric pressure. Nitrogen was selected as a diluent, and, in accordance with previous studies, a total pressure of 7 psia (362 mm Hg abs) was chosen. The resulting conditions, with appropriate tolerance, are represented by the black rectangular block in Figure 4.

Carbon dioxide is a waste product of respiration and must be removed from the atmosphere to allow proper carbon dioxide rejection by man. The effects of short-duration exposure to high carbon dioxide concentrations or prolonged exposure to moderate concentrations are deleterious to proper functioning caused by interference with basic physiological processes. Carbon dioxide partial pressure of 8 mm Hg and below are considered safe for prolonged missions. As the carbon dioxide concentration is reduced, the size of removal equipment increases. There is a point at which an adequate safety margin carbon dioxide concentration is balanced by economical operation of the removal subsystem. The operating condition of 3 to 6 mm Hg carbon dioxide partial pressure was selected for this run in consideration of these factors.

3.2 OPERATING CREW REQUIREMENTS

The test performance was supervised by the Test Director, who had the final authority for all systems operations and the decision for test termination (except for emergency abort). He was required to be available throughout the period of manned testing.

The minimum staff required for the simulator, at all times during manned test, included a test conductor, a medical monitor, two test monitors, and a technician. The test director and all members of the minimum staff were certified for their duties in accordance with the requirements of Reference 1. All personnel were required to remain at their duty stations in the immediate proximity of the simulator except that one of the test monitors could substitute for the test conductor or the other test monitor when either was absent for meals or short errands. The medical monitor was normally in the medical room adjacent to the simulator area. The duties of the personnel were as follows:

Test Conductor--A qualified test conductor was on duty at all times during the test and was responsible for the operation of the SCS, and, as second in command, reported directly to the test director. The conductor was required to notify the director of any system malfunction or condition that might require test termination. The test conductor operated the main cabin control console. He would have initiated any emergency abort, including a medical emergency termination if he had been notified by the medical monitor that a medical emergency required test termination. He was responsible for the maintenance of a log of facility checkout and operation, and he noted important events before and during the test, including date, time, and relevant comments.

Medical Monitor, M. D. --A qualified physician, licensed to practice medicine in California, was on duty at all times during the test and was responsible for monitoring the health of the crewmen. He was required to report, to the test conductor, any requirements for crew replacement or test termination for medical reasons. He was also required to assist during any emergency.

Test Monitor No. 1--This test monitor was responsible for system monitoring, data recording, and operating the airlock control console as directed by the test conductor. He also substituted for the test conductor during absences of the latter.

Test Monitor No. 2--This test monitor was required to assist test monitor 1 in system monitoring, data recording, and during any fire, medical or other emergency. In addition, as the psychological monitor, he was responsible for administering and monitoring the behavioral and group dynamic testing, as described in Reference 1. He was required to notify the test conductor of any observed crew abnormality.

Technician--The technician reported to the test conductor and performed required maintenance. He was also responsible for facility system monitoring and data recording, and was required to assist during any fire, medical or other emergency.

Other personnel required to support the test on an as-required basis were as follows:

Test Safety Officer--The test safety officer was assigned by the Safety Department and was cognizant of the safety aspects of the facility and the test. He was responsible for ensuring adherence to safety requirements during the manned testing. He was required to advise the test director of any unsafe condition or procedure.

Contaminant Control Officer--The contaminant control officer was responsible for the sampling and the analyses that were required to monitor the cabin atmosphere and water system contaminants. He was required to notify the test conductor of any abnormal cabin atmosphere or water system contaminant level. He was assisted in these duties by an engineer and two laboratory chemists.

Microbiologist--The microbiologist was responsible for the microbial sampling and the analyses that were required to ascertain that safe levels of microbial populations were maintained within the SCS atmosphere, water supply, and equipment. He was required to notify the test conductor of any abnormal or unsafe microbial levels. He was assisted in these duties by two microbiologists and a laboratory technician.

Technicians--Additional technicians reported as required to the test conductor and supported the on-duty technician by performing required tasks to maintain test success.

The SCS operating staff requirements for the 60-day test are outlined in Table 8.

Table 8 (page 1 of 2)

SPACE CABIN SIMULATOR OPERATING STAFF REQUIREMENTS

Position	Duties	Required	Number*
Test Director	Overall guidance	On Call	1
Test Conductor	Primary operational responsibility Contact with test director Operate main cabin control console Maintain facility log	Continuous	4
Medical Monitor (M.D., licensed to practice in Calif.)	Monitor health, safety of crew Assist in event of emergency	Continuous	4
Test Monitor No. 1	Monitor life support system Record performance data Operate air-lock control console	Continuous	4
Test Monitor No. 2	Administer and monitor behavior and group dynamic testing Review and maintain test subject work-rest cycle Assist test conductor or test monitor No. 1 as required	Continuous	4
Technician	Perform or assist in maintenance or repair of test equipment or facility Assist in emergency Monitor system performance and record data	Continuous	4
Test Safety Officer	Monitor safety conditions	On call	1
Contaminant-Control Officer	Sample and analyze SCS atmosphere and water recovery subsystems	Daily	1
Assistants:	Assist in analysis of atmosphere and water	Daily	
Chemical Engineer			1
Chemical Technician			2

*Note: The number of personnel is adjusted to indicate the requirements for an average work week of 40 to 42 hours. Continuous monitoring (168 hours per week) requires four qualified people for each position.

Table 8 (page 2 of 2)

Position	Duties	Required	Number*
Microbiologist	Obtain samples and analyze for microbial contaminants from SCS, test subjects and water recovery subsystems	Daily	1
Assistants:	Assist in analysis of microbial samples	Daily	
Microbiologist			2
Technician			1
Additional Technicians	Electrical or mechanical repairs	On call	---
	TOTAL PERSONNEL		30

*Note: The number of personnel is adjusted to indicate the requirements for an average work week of 40 to 42 hours. Continuous monitoring (168 hours per week) requires four qualified people for each position.

3.3 SAFETY RULES

Safety rules applied to the personnel who operated the chamber and to the test crew within the chamber. These rules were intended to control the minimum number and qualification of personnel to ensure an adequate staff for handling emergencies, to control the access of visitors to the test area, to restrict the materials that were passed into the chamber from a standpoint of flammability or toxicity, and to define the requirements for communications between the test crew and the operating crew. Rules that applied to the personnel inside the chamber prevented smoking, restricted storage of trash and flammable materials, and designated a safety monitor.

3.4 EMERGENCY PROCEDURES

The following subsection outlines the procedures established to prevent injury to personnel and damage to equipment in the event of a system failure or malfunction. In addition, procedures were defined that would have immediately terminated the test if there had been a fire or explosion. These procedures are included in the following basic categories.

Test Contingency Procedures--These procedures were to be initiated if there was a system malfunction or a component failure that, if uncorrected, could produce an alert level or endanger the health and safety of the crew. During the 60-day test period, these procedures were used to correct the equipment malfunctions that are noted in Section 4, Test Results.

Faulty components or system failures were pinpointed by the outside test personnel through the data and alarm signals monitored on the Life Support Monitor Console; the Gas Analyzer Console, the Atmospheric Supply Control Console, or by the crew members during routine observations, data gathering, initial investigation, or as directed by outside test personnel.

The faulty component or system was deactivated and an alternate or standby system was activated. Generally, each SCS system had a reserve or alternate system that could be safely used for a specified length of time without compromising the normal SCS operation. During this time, repair of the primary systems or replacement of faulty components was accomplished.

The repairs or replacements of faulty equipment installed within the SCS were accomplished by the crew members with verbal assistance and spare parts from outside personnel. Provisions were made in these procedures for sending in, by means of the airlock, a qualified technician and/or an engineer to accomplish major repairs; however, this was not required during the 60-day test.

Test Termination Procedures--These procedures were to be initiated if a system malfunctioned, if a component failed, or if there was an emergency that could not be corrected by the test contingency procedures. These procedures provided for an orderly unscheduled termination of the test, while providing for crew safety. The speed with which the SCS atmospheric pressure was returned to sea level depended on the nature of the problem. These procedures were never initiated during the 60-day test.

Alert Procedures--These procedures were to be initiated if there was smoke or an excessive rise of trace contaminants within the cabin. The duration of the alert status depended on the problem: whether it remained static, increased, decreased slowly or rapidly, etc. During the 60-day test, an alert occurred on day 50 when an alarm was initiated by the smoke-indicating unit; however, this alarm was determined to be false by the inside and outside monitoring procedures and the alert was cancelled.

Emergency Abort Procedures--These procedures were to be initiated only if there was a fire or an explosion within the cabin, and they required cabin and airlock repressurization in a maximum time of approximately 35 sec. In addition, these procedures initiated the following events automatically:

1. Activate the gaseous nitrogen flood system.
2. Terminate all inside power except the TV and intercom systems.
3. Activate the emergency lights.
4. Terminate the hot and cold Coolanol-35 and hydrogen supply to the cabin.
5. Activate the emergency water spray system inside the cabin.
6. Equalize the airlock and cabin pressures.

These procedures were never initiated during the 60-day test.

3.5 PASS-THROUGH OPERATIONS

Because of space limitations and safety considerations, a 60-day supply of expendables was not stored within the cabin. Therefore, the resupply of food, data sheets, laundry, spare parts, and equipment was accomplished through the two 18-in. diameter pass-through ports. In addition, the 150-cu-ft airlock was used to install and remove large items.

During the 60-day test, two pass-through operations were scheduled each day for normal resupply; collection of chemical and microbial samples; and replacement of maintenance items, such as the filters, charcoal columns, and resin columns for the water recovery subsystem. Additional pass-through operations were accomplished as required to replace malfunctioning equipment and spare parts. The two small pass-through ports were normally utilized; however, the airlock was used eight times for the removal or installation of large equipment. These airlock operations consisted of two operations each (removal and return) for the bicycle ergometer twice, carbon dioxide concentrator vacuum pump module once, and waste management subsystem once.

Section 4

TEST RESULTS

This section contains the engineering results from the 60-day test. A description of the equipment and an evaluation of the performance of life-support subsystems is included. In addition, an evaluation of piggy-back equipment, provided to McDonnell Douglas by various contractors and/or governmental agencies, is included.

4.1 GENERAL SYSTEM DESCRIPTION

The 60-day test was conducted in the McDonnell Douglas Space Cabin Simulator (SCS) which was designed to provide operating experience with life-support systems for manned spacecraft. The SCS is a double-walled steel cylinder, 12 ft in diameter by 40 ft long, with an empty volume of 4,100 cu ft. The annular space between the inner and outer chamber walls is normally evacuated slightly below cabin pressure to ensure that all leakage is outward to provide realistic simulation of a space station environment. The chamber is insulated with four inches of thermal insulation to minimize heat loss. A 150-cu-ft airlock and two 18 in. diameter pass-through airlock ports are provided to permit the interchange of personnel and equipment during manned tests. A complete description of the SCS and related test facilities is contained in Appendix A of this report.

The environmental control and life-support equipment provided support for a four-man crew under conditions comparable to those encountered by an earth-orbiting space station operating on a 1-year mission with 60- to 90-day resupply periods. This life-support equipment included an atmosphere supply and pressurization system which recovered oxygen from metabolic waste carbon dioxide and maintained the cabin pressure and composition; a water management system which recovered potable water from urine and humidity condensate, and water for personal hygiene from used wash water; an atmosphere purification and control system which removed carbon dioxide and other trace contaminants from the cabin atmosphere; thermal and humidity control subsystems which removed the sensible and latent heat load generated within the cabin; and a waste management subsystem which processed and stored fecal waste material.

The major portion of the life-support system was installed within the cabin, and the test crew was required to maintain, monitor, and repair this equipment. The two-gas atmosphere control subsystem, a component of the atmosphere supply and pressurization system, was installed outside the SCS because of space limitations. The electrolysis unit, also a component of the atmosphere supply and pressurization system, was an interim unit of commercial construction which could not function at the 7 psia cabin pressure, and, therefore, was also installed outside of the SCS.

4.2 ATMOSPHERE SUPPLY AND PRESSURIZATION

This system consisted of a Sabatier reactor which produced water from carbon dioxide and hydrogen, a water electrolysis unit which produced oxygen and hydrogen from the Sabatier water, and a two-gas atmosphere control subsystem.

4.2.1 System Operation

The recovery of oxygen was accomplished by the Sabatier reactor process, which involves the hydrogenation of carbon dioxide to yield water and methane. The methane and noncondensible gases were dumped overboard and the condensed water was periodically pumped to the water electrolysis unit (outside the SCS) where the water was electrolyzed to recover oxygen, which was returned to the cabin, and hydrogen, which was recycled back to the reactor. Auxiliary supplies of water, hydrogen and carbon dioxide were provided to allow continuous testing on remaining equipment if one of the components in the loop malfunctioned.

The oxygen produced by the electrolysis unit was returned to the cabin by means of the two-gas atmosphere control subsystem. This subsystem maintained the proper oxygen partial pressure and total pressure within the SCS. The major components of this subsystem were an oxygen partial pressure control unit, a total pressure control unit, and a backup oxygen supply (in addition to the normal supply from the electrolysis unit).

The Sabatier reactor process produces water and methane. Since the methane must be discarded by venting to space, the hydrogen which reacted to form the methane is lost. In addition, small quantities of water vapor, unreacted hydrogen, and carbon dioxide are also lost because the reaction process is not completely efficient. These losses must be replenished to maintain the reaction utilizing one of the following modes of operation.

1. Add sufficient makeup water to the electrolysis unit to satisfy the hydrogen requirements of the Sabatier reactor to reduce all of the metabolic carbon dioxide produced. Excess oxygen is produced which must be vented overboard.

2. Add sufficient makeup water to the electrolysis unit to satisfy the cabin oxygen requirements only and operate the Sabatier reactor on the hydrogen available from the electrolysis unit. Since all of the available carbon dioxide cannot be reduced, some carbon dioxide must be vented overboard.

3. Add sufficient makeup oxygen and hydrogen to satisfy the cabin and Sabatier reactor process.

4. Same as mode 2 except additional hydrogen is added to the Sabatier reactor to reduce all available carbon dioxide.

To be compatible with the operating requirements for the commercial electrolysis unit and to simplify the Sabatier control, the oxygen recovery loop was operated in mode 1. During the 60-day test, however, as stated in the following discussion, this was not the most efficient mode of operation, which studies indicate to be mode 2.

The mass balance data for the oxygen recovery subsystem is shown in Figure 5. During this run, the Sabatier reactor was operated to process all the metabolic carbon dioxide produced, and the water electrolysis unit supplied the required hydrogen (mode 1 above). An excess of oxygen was therefore produced, and this excess was vented as shown. More makeup water was added to the circuit then would have been normal if a more conservative mode of operation had been selected, and only enough water had been electrolyzed to provide the oxygen necessary to keep up the concentration. If mode 2 had been utilized, the makeup water requirements would have been only 5.02 lb per day instead of 10.42 lb per day.

The oxygen recovery mass balance is based on the amount of carbon dioxide processed by the Sabatier reactor and the gas chromatography analysis of the reactor exhaust gases. This results in a theoretical value of 4.924 lb/day of water produced, as shown in Figure 5, compared with an actual recorded value of 4.2 lb/day. The difference between these values is attributed to the following: (1) the average reactor exhaust gas composition on the 3 days chosen for analysis indicated a good reactor performance. Several of the analyses for other days show that the reaction was not as complete and, therefore, would affect the ratio of water out to carbon dioxide in; and (2) the carbon dioxide and hydrogen sonic orifice flows were affected by pressure transients outside their calibrated ranges, which might also affect the reaction efficiency.

4.2.2 Sabatier Reactor

4.2.2.1 Sabatier Reactor Description

The Sabatier reactor was built by Garrett Corporation to McDonnell Douglas specification. Figure 6 is a schematic diagram of the Sabatier unit, and Figure 7 shows the Sabatier reactor unit with the cover removed.

Carbon dioxide entered the Sabatier unit from the carbon dioxide accumulator at a pressure of 15 to 25 psia, at a flow rate proportional to the inlet pressure through the sonic metering orifice. The hydrogen from the electrolysis unit entered the Sabatier unit through a pressure regulator and the hydrogen metering orifice and was then mixed with the carbon dioxide. The hydrogen regulator controlled the hydrogen inlet pressure as a function of carbon dioxide inlet pressure, and provided the capability of varying the mixture ratio as desired. The carbon dioxide and hydrogen reactants were mixed downstream of their respective orifices, and entered the catalytic reactor. This mixture then produced within the catalyst bed an exothermic reaction, yielding water and methane. The catalyst used in this test was nickel on Kieselguhr.

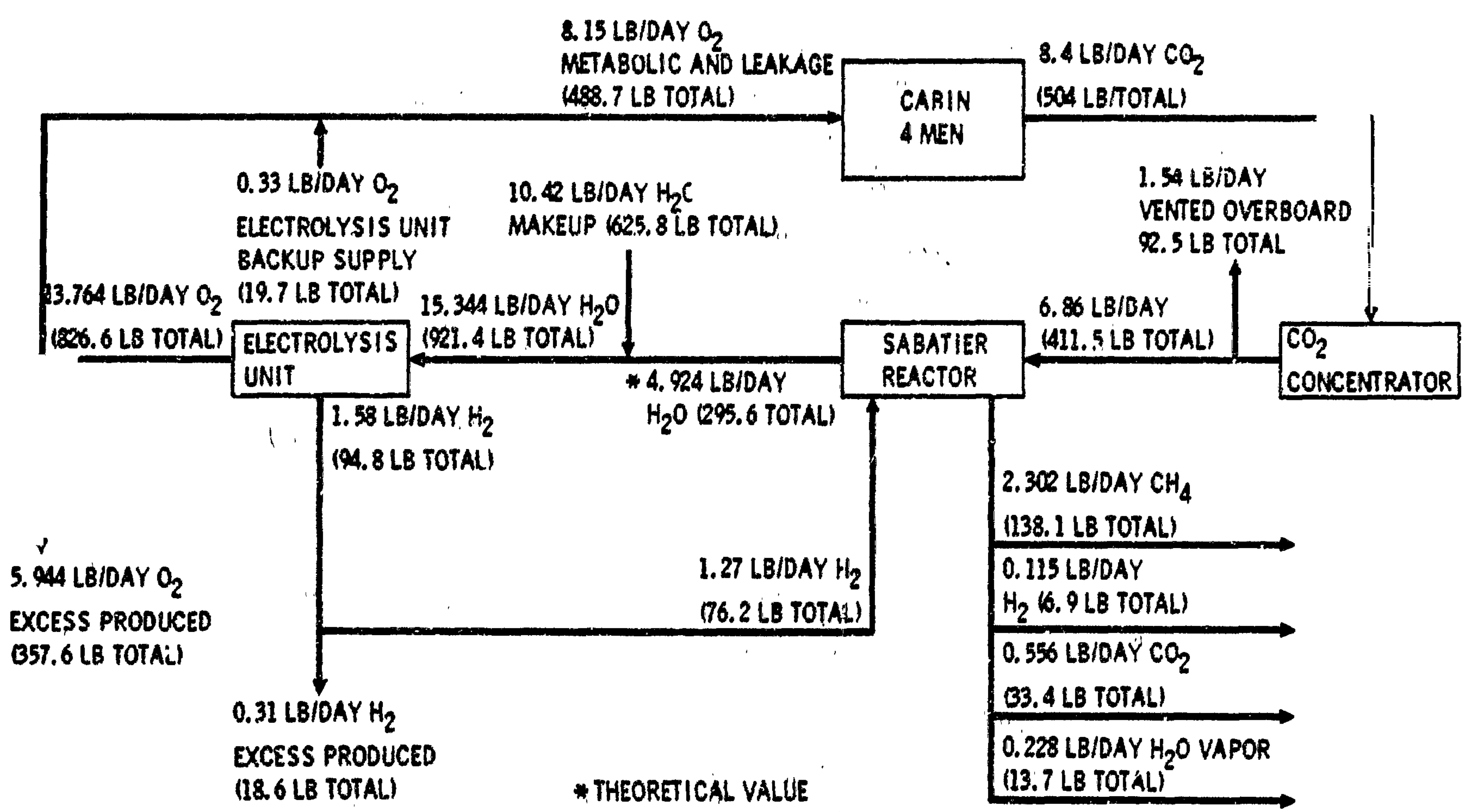


Figure 5. Oxygen Recovery Subsystem Mass Balance

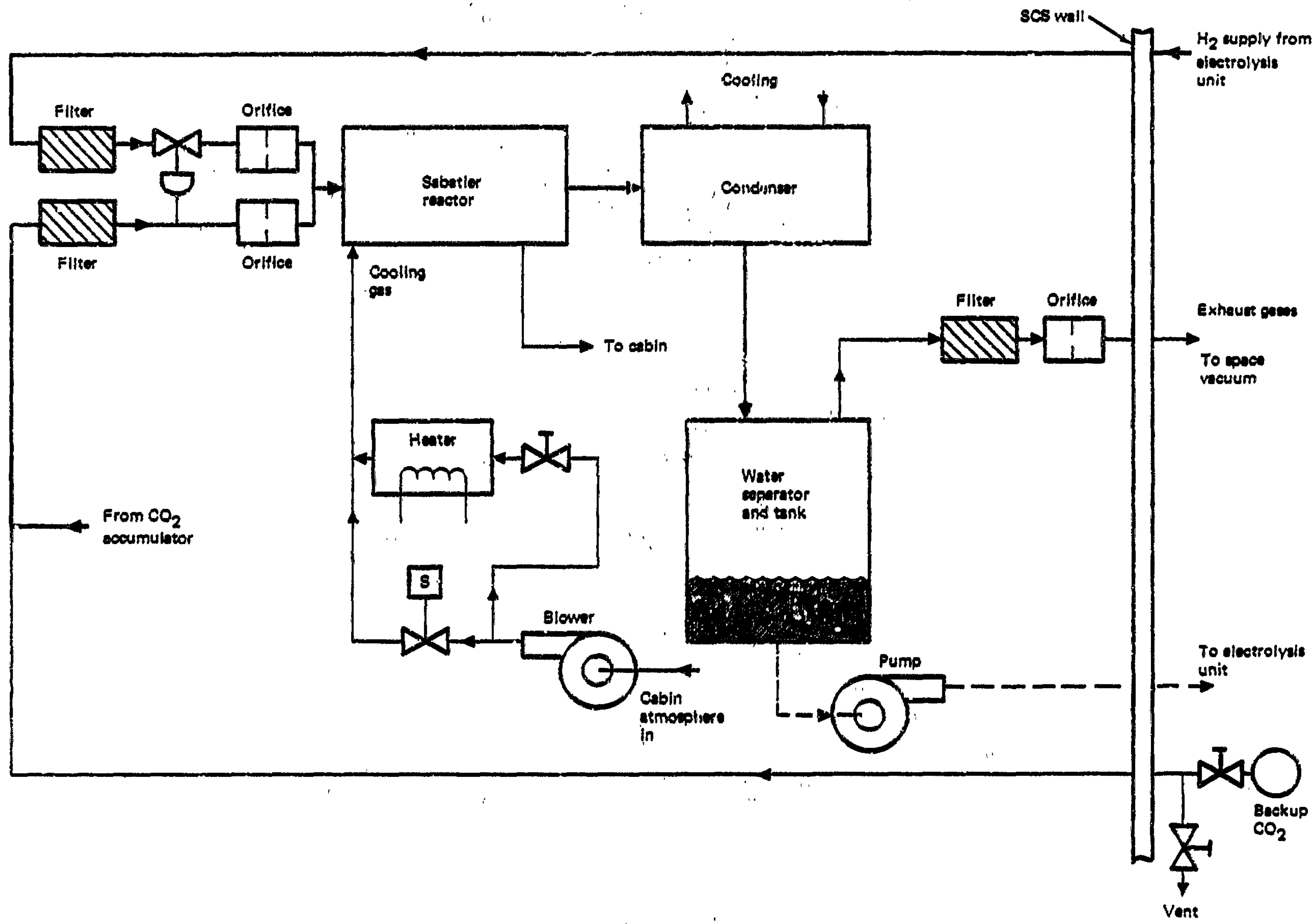


Figure 6. Sabatier Hydrogenation Unit

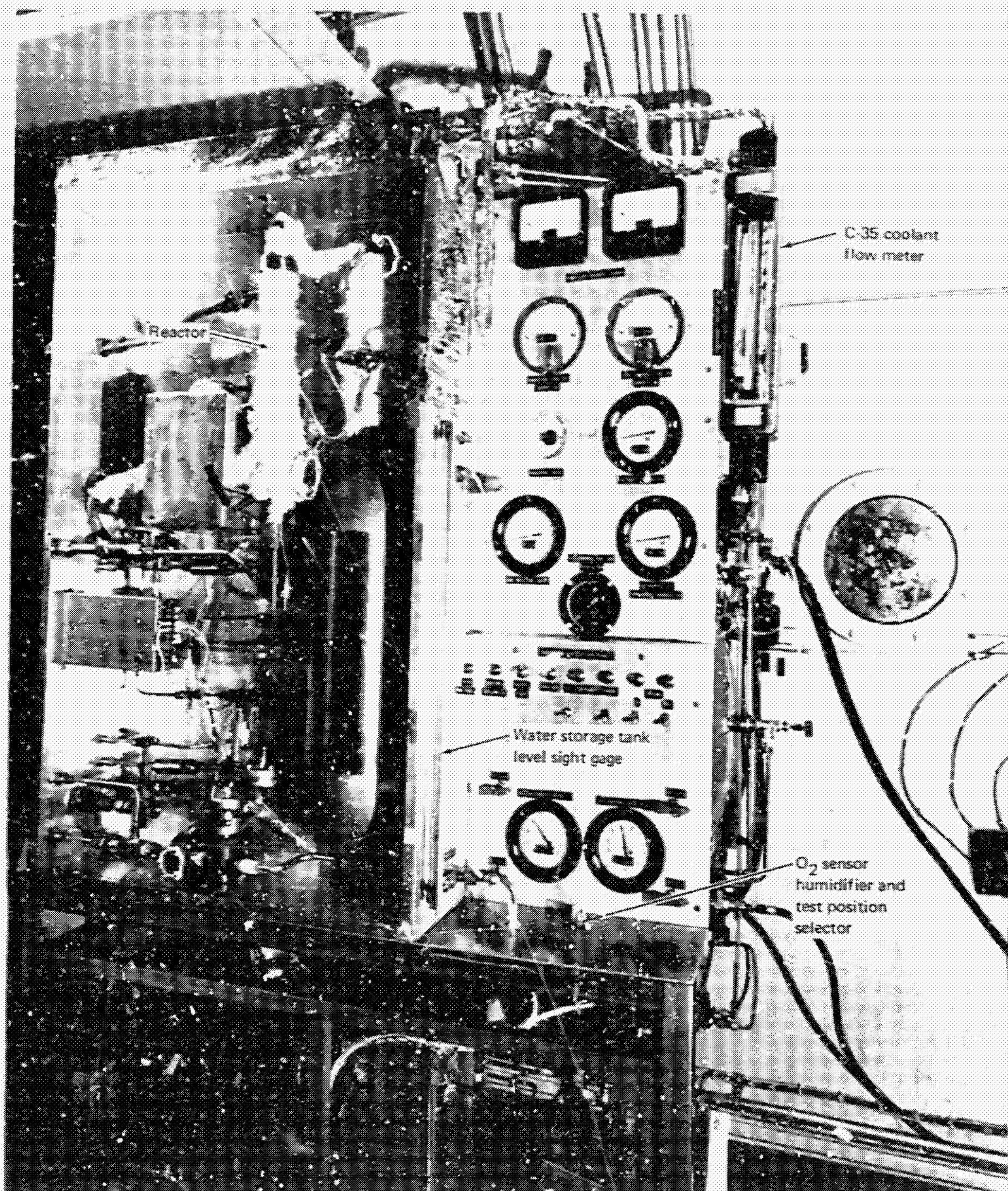


Figure 7. Sabatier Hydrogenation Unit Installation

$$CO_2 + 4H_2 \xrightarrow[\text{(exothermic)}]{\text{catalyst}} 2H_2O + CH_4$$

The heat generated by the exothermic reaction in the catalyst bed was removed by cooling air circulating around the reactor. A temperature controller and solenoid valve unit was provided for control of cooling airflow, but this unit failed and was not used during the later portion of the test, as explained below. The solenoid valve was actuated by a temperature sensor embedded in the catalyst. An electric heater, controlled by a manual switch, provided the energy required to bring the reactor bed up to operating temperature at startup. The reactor bed was heated by opening the manual bypass valve in the cooling air circuit, thereby heating the inlet air in the heater and passing it over the reactor bed.

The reaction products, methane and water vapor, flowed to the water separator, together with any unreacted gases, where they were cooled and the water vapor condensed. Cooling was provided by Coolanol 35 supplied to the water condenser at 45°F. The condensed water was accumulated in the water tank; gaseous methane, unreacted carbon dioxide and hydrogen, and small amounts of water vapor were discharged to vacuum through an orifice. This discharge orifice was sized to maintain reactor operating pressure at approximately 7 psia during the maximum carbon dioxide processing rate of 12 lb/day.

The quantity of water accumulated in the Sabatier water tank was measured by a sight gage. When the water level reached the full mark, an electrical switch was manually closed. Closure of this switch opened the outlet solenoid valve and activated the water pump, which transferred the water to the water electrolysis unit holding tank outside the cabin.

4.2.2.2 Performance Analysis

The water produced by the Sabatier reactor during the test was analyzed by procedures similar to those used on the potable water. Table 9 shows an analysis of this water, indicating the very high purity attained in the process.

Figures 8 and 9 show the carbon dioxide and hydrogen gas flow rates into the reactor as a function of pressure, based on pretest calibration of the sonic orifices that limit flows of the reactant gases. Table 10 shows the chemical analysis of the hydrogen and carbon dioxide supplied to the reactor on several days. Both the carbon dioxide and hydrogen purity is very high, and indicates successful performance by the carbon dioxide concentrator and water electrolysis units. Table 11 presents a similar analysis of exhaust gas composition. Normally, the reactor was operated near a stoichiometric misture with approximately 4:1 hydrogen to carbon dioxide ratio by volume. One data point was obtained on April 11, in which insufficient hydrogen was provided for complete reaction of the carbon dioxide. This operating mode is important because mass balance studies indicate normal operation will result in a similar hydrogen deficiency. Calculated reaction efficiencies are shown in Table 12. These have been calculated on the basis of outlet gas composition data and show the percentages of carbon dioxide and hydrogen reacted. Values of 90 to 93 percent are considered acceptable, although better values (93 to 96 percent) were observed on the reactor during bench tests.

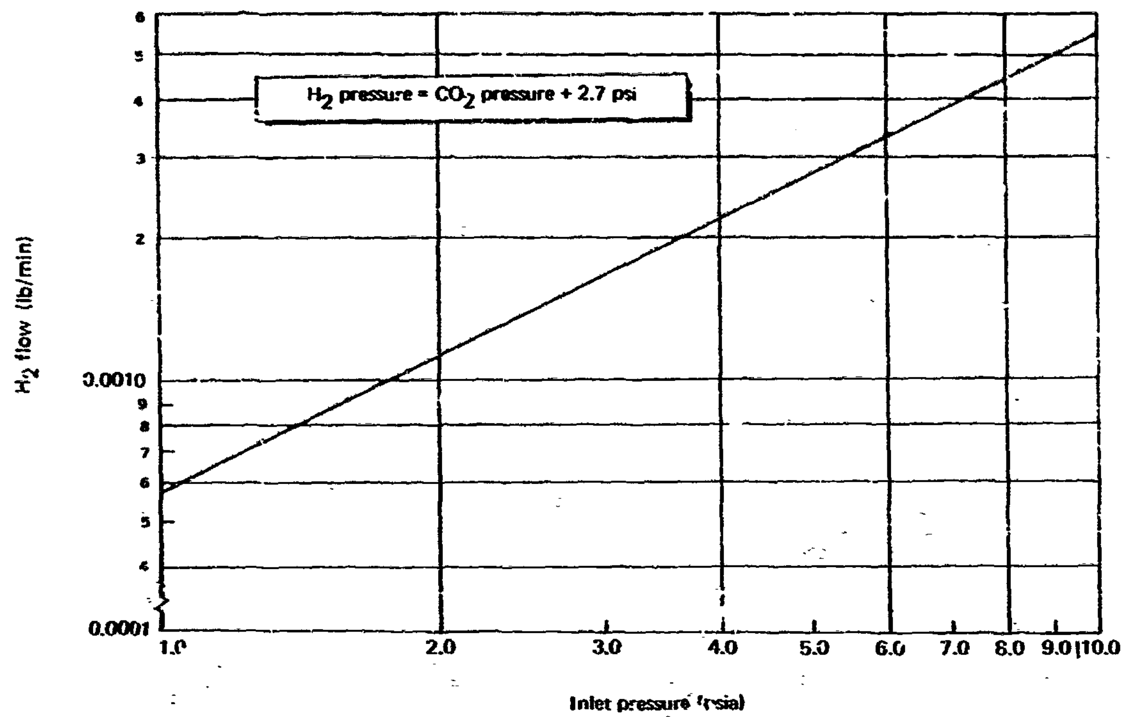


Figure 8. H_2 Flow vs Inlet Pressure Sabatier Reactor

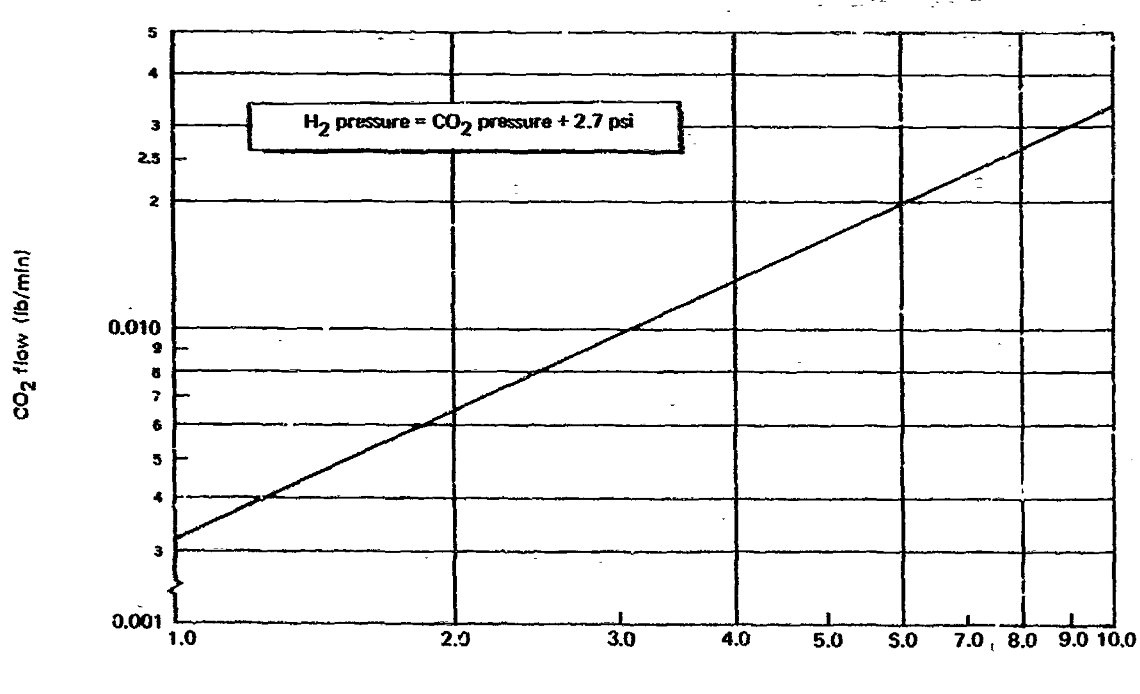


Figure 9. CO_2 Flow vs Inlet Pressure Sabatier Reactor

Table 9

SABATIER WATER ANALYSIS

Date	COD mg/l	NH_3 mg/l	Cr^{+6} mg/l	pH	Spec. Cond. µmhos/cm	Color Units	Turbidity (SiO_2) ppm
2-2-68	3.8	9.2	0.0005	6.65	21.0	19	5
2-5-68	8.6	5.8	0.0	5.95	18.0		3
2-9-68	3.1	5.3	0.0	6.85	22.5		1
4-16-68	0.0	6.3	0.0	6.30	53.0	<5	0
4-25-68	0.0	10.3	0.0	7.50	68.0	<5	0

Table 10

SABATIER INLET GAS ANALYSIS

CO_2 Purity (% Vol):			H_2 Purity (% Vol):		
Date	O_2	N_2	Date	O_2	N_2
2-29-68	0.00	0.0	2-28-68	0.04	0.3
3-07-68	0.08	0.6	3-07-68	0.08	0.6
3-14-68	0.05	0.1	3-14-68	0.16	0.7
3-21-68	0.02	0.2	3-21-68	0.05	0.3
4-02-68	0.05	0.4	4-02-68	0.11	0.7

Table 11

SABATIER EXHAUST GAS COMPOSITION*

(% Vol)

Date	CH_4	H_2	CO_2	O_2	N_2	CO (ppm)	H_2O (calc.)
2-20-68	55.4	33.3	6.1	0.4	3.3	----	1.5
2-21-68	63.9	26.9	6.4	0.2	1.1	----	1.5
2-28-68	62.7	27.5	6.0	0.8	1.5	----	1.5
4-05-68	67.2	21.5	4.8	0.7	4.3	----	1.5
4-11-68	68.2	0.0**	17.8	1.9	10.6	<200	1.5
4-15-68	64.8	25.4	5.7	0.4	2.2	<200	1.5
4-16-68	66.2	25.5	5.1	0.1	1.6	<200	1.5

*CH_4, H_2, CO_2, O_2 and N_2 analyses increased or decreased in proportion to produce 100%.

**H_2 pressure was low and a stoichiometric mixture was not maintained.

Table 12

SABATIER PERFORMANCE

Date	Carbon Dioxide Reaction Efficiency (%)	Hydrogen Reaction Efficiency (%)
2-20-68	90.0	89.2
2-21-68	91.0	90.5
2-28-68	93.0	90.2
4-05-68	93.3	92.6
4-11-68	79.2*	100.0*
4-15-68	92.0	91.1
4-16-68	92.5	91.3

*Hydrogen pressure low and stoichiometric mixture was not maintained.

The only problem encountered with the operation of the Sabatier reactor involved repeated failures of the solid-state temperature control. After five unsuccessful attempts to provide a workable solid-state temperature controller, the unit was operated on manual control for the last 26 days of the test. The catalyst showed no visible signs of deterioration upon test completion.

4.2.3 Water Electrolysis

The water electrolysis unit was sized to supply 110 percent of the maximum hydrogen gas flow required to process the carbon dioxide production of the four crew members in the Sabatier reactor. This provided for flexibility to operate in several modes, outlined above, that may be typical in closed life-support systems. The module was constructed by the Electrolyser Corporation, Ltd., of Toronto, Canada, to satisfy McDonnell Douglas requirements for gas flow rates, pressure and purity. As a result of sizing to meet hydrogen requirements, the unit is capable of supplying more than the required daily oxygen consumption of the four-man crew, and some venting occurred during the test.

Figure 10 schematically presents the water electrolysis unit. During normal operation, water from the Sabatier unit was pumped at intervals to the water storage tank outside the SCS. Distilled makeup water was added from a separate source as required. The unit was designed to electrolyze the water and to collect, compress, and purify the generated hydrogen and oxygen.

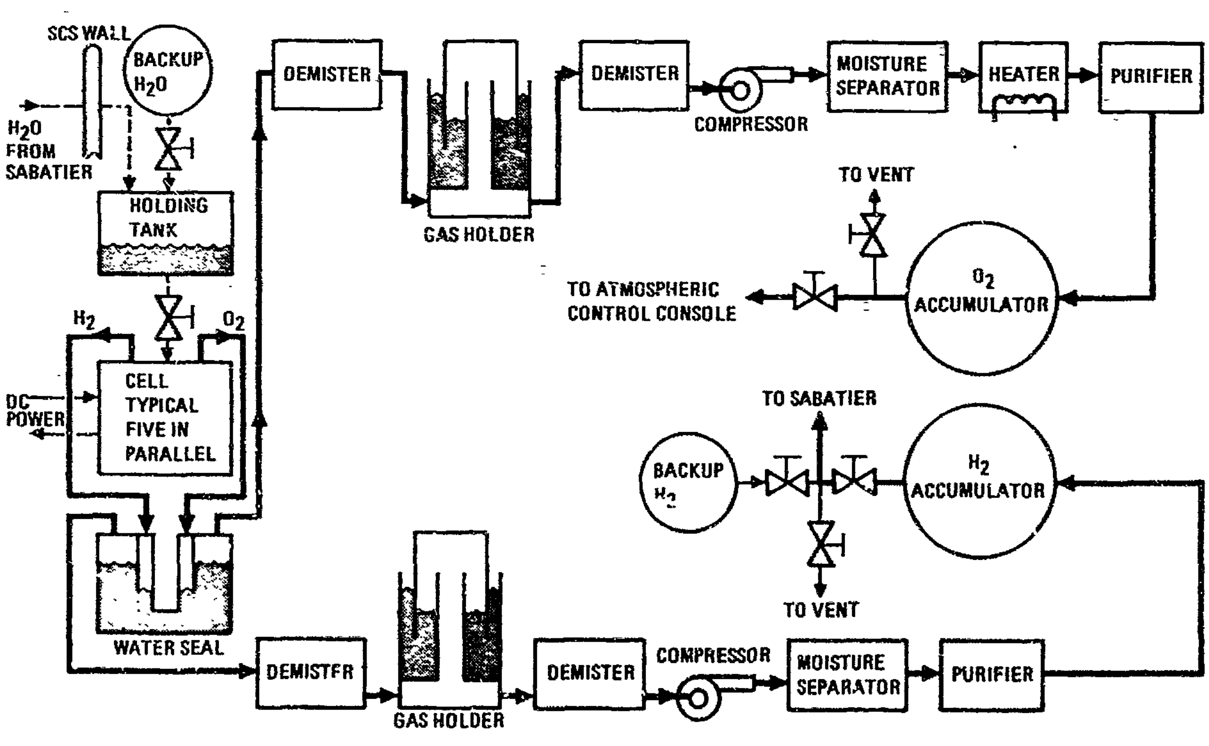


Figure 10. Water Electrolysis Unit

Figure 11 is an overall view of the water electrolysis unit, which is capable of producing 20 cu ft of hydrogen and 10 cu ft of oxygen per hour at rated current of 250 amps. This unit consists of an air-cooled transformer and rectifier, five Stuart electrolytic cells connected electrically in series, a water seal, a low-pressure gas holder for each gas, an air-cooled electrically driven compressor for each gas, a purification system for each gas, storage and reserve tanks for each gas, all interconnecting piping, various protective devices, and automatic controls.

The five electrolytic cells receive dc power from the rectifier. When dc flows through the cells, the water is broken down into hydrogen and oxygen gases. The rate of formation of hydrogen and oxygen is directly proportional to the amount of current supplied.

The low-pressure holders collect gas from the cells at a pressure of approximately 5 in water. Each gas is drawn from its low-pressure holder, compressed to a pressure of 50 psig, purified, and transferred to its accumulator. Backup supplies of water, hydrogen and carbon dioxide were also connected to the system to provide continuous testing of remaining equipment in the event of malfunction of one of the components in the loop.

Several malfunctions in the water electrolysis unit occurred during the test. However, a flight-type on-board unit would not be subjected to the major failure problem, that of the gas compressors, which suffered several failures of diaphragms, bearings, and valves. The gases that were produced were of acceptable quality and high purity as shown in Table 10.

4.2.4 <u>Two-Gas Atmosphere Control</u>

4.2.4.1 Description of Two-Gas Control

The two-gas atmosphere control subsystem maintained the proper oxygen partial pressure and cabin total pressure within the SCS. The major components of this subsystem were a polarographic oxygen partial pressure sensor, a total pressure sensor, nitrogen supply and delivery plumbing, backup oxygen supply (in addition to the normal supply from the electrolysis unit) and delivery plumbing, and the control console. A schematic diagram of this subsystem is shown in Figure 12.

During normal operation, oxygen was supplied to the atmospheric supply control unit by the electrolysis unit. High-pressure oxygen cylinders were used as a backup supply and for initial atmospheric loading of the cabin. Nitrogen was stored in high-pressure cylinders. Sensing for the two-gas atmosphere control was provided by a Beckman Polarographic oxygen partial pressure sensor located near the rear main cabin diffuser and by a strain-gage pressure sensor located within the equipment cabinet.

The atmospheric supply control subsystem operated on a periodic pulse basis (Reference 8). Timers established the pulse durations; during normal operation, a pulse occurred every 3 to 10 minutes. The subsystem admitted oxygen to correct for low-oxygen partial pressure. If the oxygen partial pressure was satisfactory, and the cabin chamber pressure was low, nitrogen

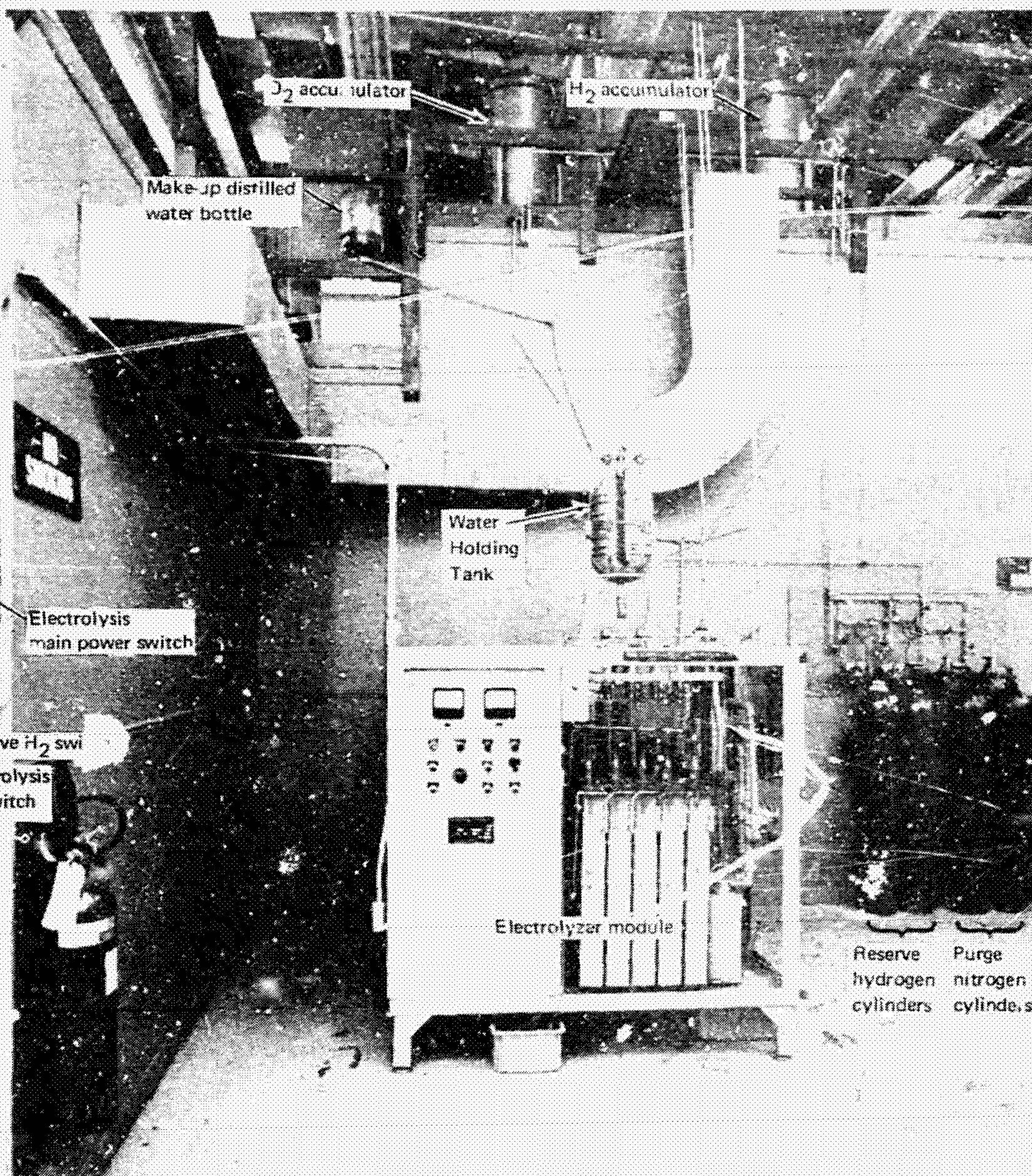


Figure 11. Overall View of the Water El.ctrolysis Unit

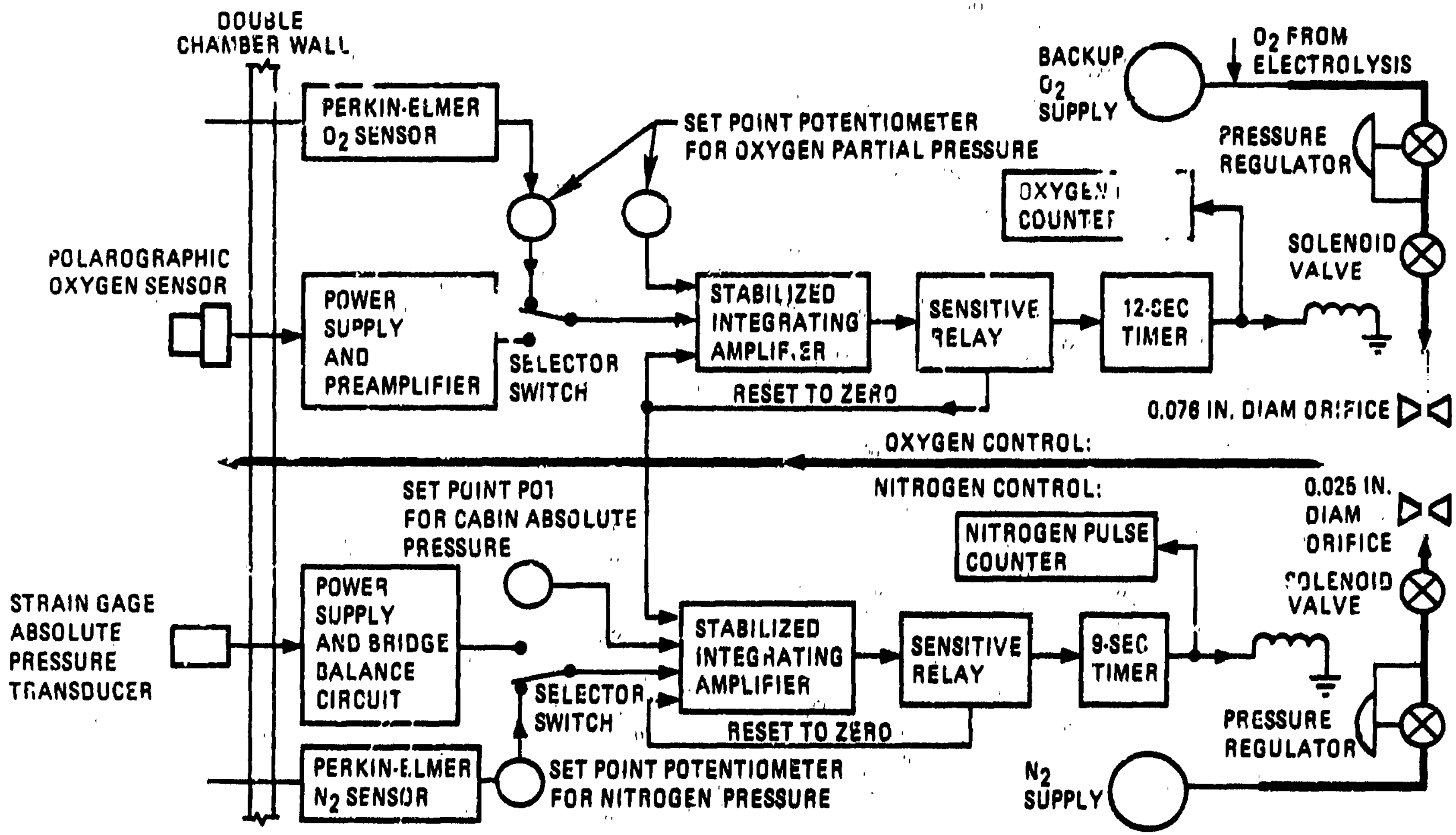


Figure 12. Atmosphere Supply Control Subsystem

was added. Each pulse of the oxygen and nitrogen control units admitted a calibrated quantity of gas and was registered by pulse counters. A count of the total pulses indicated total usage of each gas.

The amount of nitrogen used depended upon cabin leakage, and the amount of oxygen depended upon metabolic requirements as well as leakage. The output of the oxygen partial pressure sensor was indicated by the meter on the control console. This reading was compared with that of the paramagnetic analyzer in the Gas Analysis Console twice each day, and appropriate adjustments were made in the calibration of the system.

The use of the polarographic sensor was discontinued as an oxygen partial pressure controller on day 14 to permit evaluation of the NASA Langley Research Center (NASA/LRC)-furnished mass spectrometer sensor system as a controller. The total pressure control was discontinued on day 28, with the NASA/LRC unit used to furnish a nitrogen partial pressure signal for control of the diluent. Figure 12 includes a diagram indicating the method for introducing these signals from the mass spectrometer to the atmosphere supply control.

4.2.4.2 Description of Advanced Mass Spectrometer Sensor

The flight-type mass spectrometer sensor system, manufactured by the Perkin-Elmer Corporation under NASA Contract No. NAS1-6387, was used to analyze the cabin atmosphere for oxygen nitrogen, carbon dioxide, and water vapor. This unit was used as an auxiliary sensor of the atmosphere composition to evaluate its performance in this application during an extended period. Figure 13 shows this unit and the associated pumping facility required to provide simulated space vacuum.

The four-gas sensor consisted of a single-focusing 90° magnetic-sector-type mass spectrometer. Ions were supplied to the analyzer from a nonmagnetic dual electron gun. The ionizing beam of electrons was obtained from one of two tungsten-rhenium alloy wire filaments. The object slit plate of the ion source also formed the mounting plate for the ion source components on one side and the Z-axis focus lens elements on the other side.

The mass spectrometer asssembly was mounted in a thin-walled housing which served as an integral part of the collector flange assembly and analyzer envelope. A permanent magnet provided the magnetic field to accomplish mass resolution as the ions passed through the envelope section of the analyzer. An adjustable ion collector was used to collect and separate the four gases to be analyzed. The four separated gases were water, nitrogen, oxygen, and carbon dioxide, which were referenced to an ion mass-to-charge ratio of m/e 18, m/e 28, m/e 32, and m/e 44.

A viscous pressure divider inlet system admitted a sample of the cabin atmosphere to the ion source. It consisted of a single two-meter capillary line, a pumpout line, and a platinum aperture molecular inlet leak at their conjunction. A solid-state amplifier was provided for each of the collected ion currents.

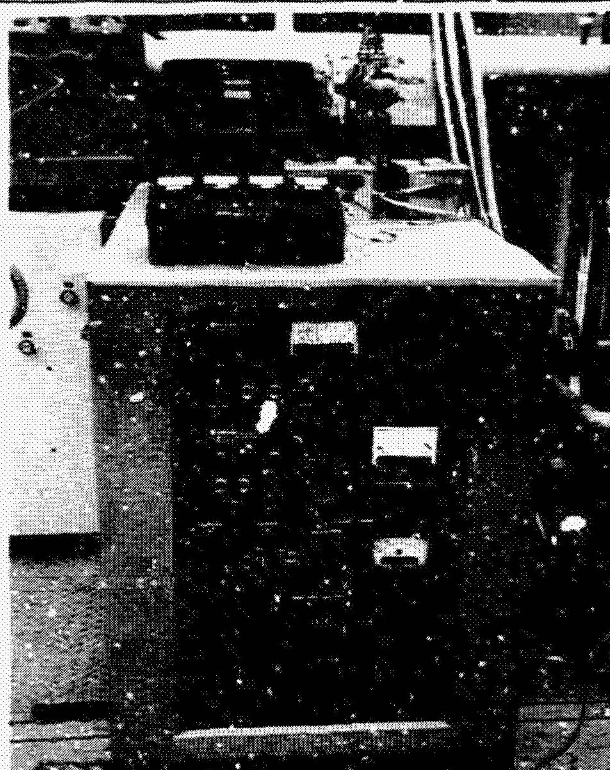


Figure .3. Advance Four-Gas Mass Spectrometer

In addition to the four ion current amplifiers, the sensor electronics subsystem consisted of three modules that provided the electronic functions necessary for the operation of the analyzer. First, there was a filament supply and emission regulator that supplied an ac voltage to the filament.

This was a closed-loop control system that sensed the ionizing current collected at the anode of the ion source and used this as feedback current to control the filament power so that the ionizing current remained constant. System considerations required that this module be floated above ground at the anode potential. An inverter was used for this purpose and its pulse-width modulated output drove the filament.

The electrode bias supply provided the voltages to the various focusing electrodes in the ion source. It consisted of a single inverter with a multiple winding output. Series voltage regulators operated from two of the rectified outputs; these were used to compensate for variations in two of the other outputs. The result was three stacked high-voltage outputs, two that were regulated and one that was unregulated. These outputs were loaded by a resistance voltage divider network.

The detector power supply consisted of a single free-running inverter which drove B+ and B- series regulators. These regulators supplied +10 and -10 V to the detectors.

4.2.4.3 Operating Data

The average oxygen partial pressure, as indicated by the Beckman paramagnetic analyzer, was 155 mm Hg during the test; the average total pressure was 362 mm Hg. Figure 14 shows the daily variation of oxygen partial pressure and total pressure.

The mass spectrometer was calibrated 41 times during the 60-day test. Each calibration was performed by use of a known sample mixture of nitrogen, oxygen, and carbon dioxide which was introduced at a known pressure to the instrument. The calibration factor resulting from each calibration is shown on Figure 15. Water vapor could not be accurately introduced to the mass spectrometer, and, therefore, the channel indicating water content could not be calibrated.

The reliability of the instrument was very good throughout the 60-day test period. The only problems of importance were changes in emission filament resistance and failure of the roughing pump drive belt on the vacuum system. The emission filament was found to have increased in resistance during the first ten days and again between the 43rd and 46th day of the 60-day test. The emission regulator was replaced or modified to accommodate the higher filament resistance in both cases.

Overall performance of the mass spectrometer can perhpas best be assessed by examination of the data obtained during the 60-day test. Calculations were made based on a daily average of the recorded oxygen pressure readings. (NOTE: Calculations were based on oxygen pressure because a data comparison could be made between the mass spectrometer and the Beckman paramagnetic sensor installed in the Gas Analyzer Console. Cabin nitrogen pressure was only available from the mass spectrometer.) These calculations show the standard deviation to be 4.5 mm Hg for oxygen, with 159 mm Hg as the mean oxygen partial pressure. This mean oxygen pressure value is 4-5 mm Hg higher than that based on data from the Beckman paramagnetic oxygen sensor. A close examination of data and calibration factors for the first 14 days of the test, however, indicates that the changes in emission filament resistance may have caused errors sufficient to invalidate the data taken during this period. The data taken for day 14 through day 60 can be grouped into three categories. The categories are (1) day 14 through day 22, during which electron gun 1 was operating; (2) day 25 through day 38, during which electron gun 2 was operating; and (3) day 41 through day 60, following a slight change in calibration that occurred when a drive belt on the vacuum system failed on day 38. Table 13 indicates these categories and shows how the calibration factor varies from the computed mean calibration factor value. The standard deviation was also computed for the calibration factor and was found to be 1.11 percent of nitrogen and 1.08 percent for oxygen. Most of this error appears to be due to the inaccuracy of the output meters. It was noted that the calibration factor showed a tendency to increase toward the end of each period, thus giving a negative value when it was subtracted from the computed mean calibration factor value. The reason for this is not clear, except that it may be related to some continued increase in emission filament resistance.

Table 13

SENSITIVITY VARIATION OF MASS SPECTROMETER UPON PERIODIC CALIBRATION

Test Day	X_{N_2} Torr/Volt	X_{O_2} Torr/Volt	$\frac{X_{N_2} - \bar{X}_{N_2}}{\bar{X}_{N_2}}$ PERCENT	$\frac{X_{O_2} - \bar{X}_{O_2}}{\bar{X}_{O_2}}$ PERCENT	
15	68.52	78.08	0.45	0.03	First 14 days of data eliminated due to resistance change of emission filament.
16	67.98	78.19	-0.34	0.17	
17	68.50	78.42	0.43	0.46	
18	67.87	77.93	-0.50	-0.17	
19	67.56	77.26	-0.95	-1.03	
20	68.36	77.91	0.22	-0.19	
22	68.68	78.61	0.69	0.70	
Mean	68.21	78.06			
25	71.85	82.83	1.67	1.70	Subsystem sensitivity changed when electron gun No. 2 was switched on during the 24th day.
26	70.71	81.70	0.06	0.31	
27	71.85	82.45	1.67	1.23	
28	71.28	82.07	0.86	0.76	
29	70.43	81.33	-0.34	-0.15	
31	70.10	80.46	-0.81	-1.22	
33	70.64	81.33	-0.04	-0.15	
36	70.15	80.96	-0.74	-0.60	
38	69.06	79.87	-2.28	-1.94	
Mean	70.67	81.45			
41	65.25	75.18	1.49	1.04	Mass spectrometer sensitivity again changed after operating for a period of time with a drive belt failure on the vacuum system. Belt failed on 38th day.
42	65.01	74.86	1.12	0.60	
43	64.77	74.86	0.75	0.60	
45	65.25	75.18	1.49	1.04	
47	63.84	73.63	-0.70	-1.10	
50	64.07	74.86	-0.34	0.60	
52	65.01	75.49	1.12	1.45	
55	63.39	73.33	-1.40	-1.45	
57	62.94	72.44	-2.10	-2.65	
59	63.39	73.33	-1.40	-1.45	
Mean	64.29	74.41			

$$\sigma_{N_2} = \sqrt{\frac{\sum_1^n \left(\frac{X_{N_2} - \bar{X}_{N_2}}{\bar{X}_{N_2}}\right)^2}{n}} = 1.11$$

$$\sigma_{O_2} = \sqrt{\frac{\sum_1^n \left(\frac{X_{O_2} - \bar{X}_{O_2}}{\bar{X}_{O_2}}\right)^2}{n}} = 1.08$$

where: $\bar{X}_{N_2}$ = mean calibration factor for N_2 - torr/volt

$\bar{X}_{O_2}$ = mean calibration factor for O_2 - torr/volt

X_{O_2}, X_{N_2} = calibration factor for O_2 and N_2 torr/volt

σ_{N_2} = standard deviation for N_2 - %

σ_{O_2} = standard deviation for O_2 - %

n = number of samples

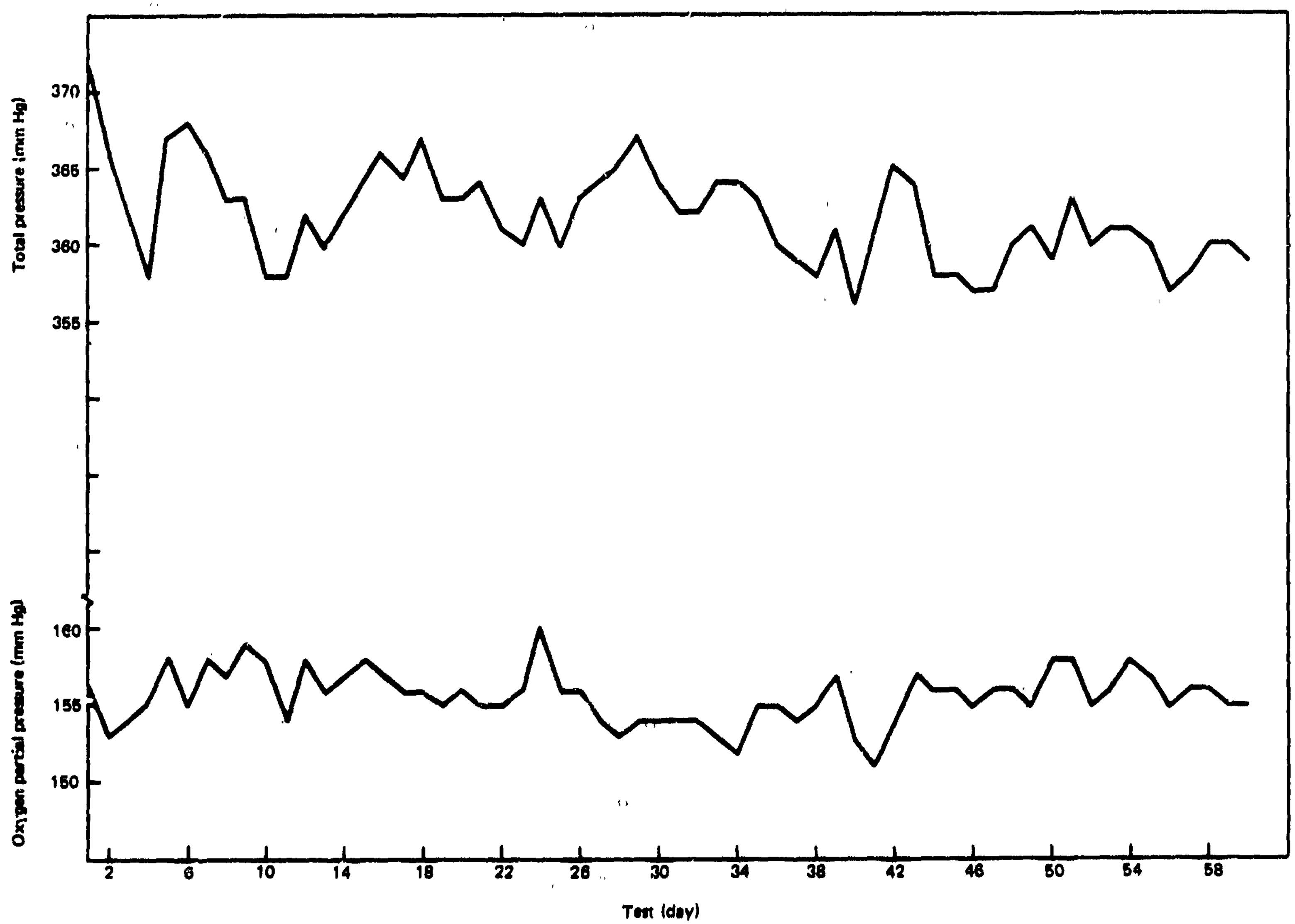


Figure 14. Daily Average Oxygen Partial Pressure and Total Pressure

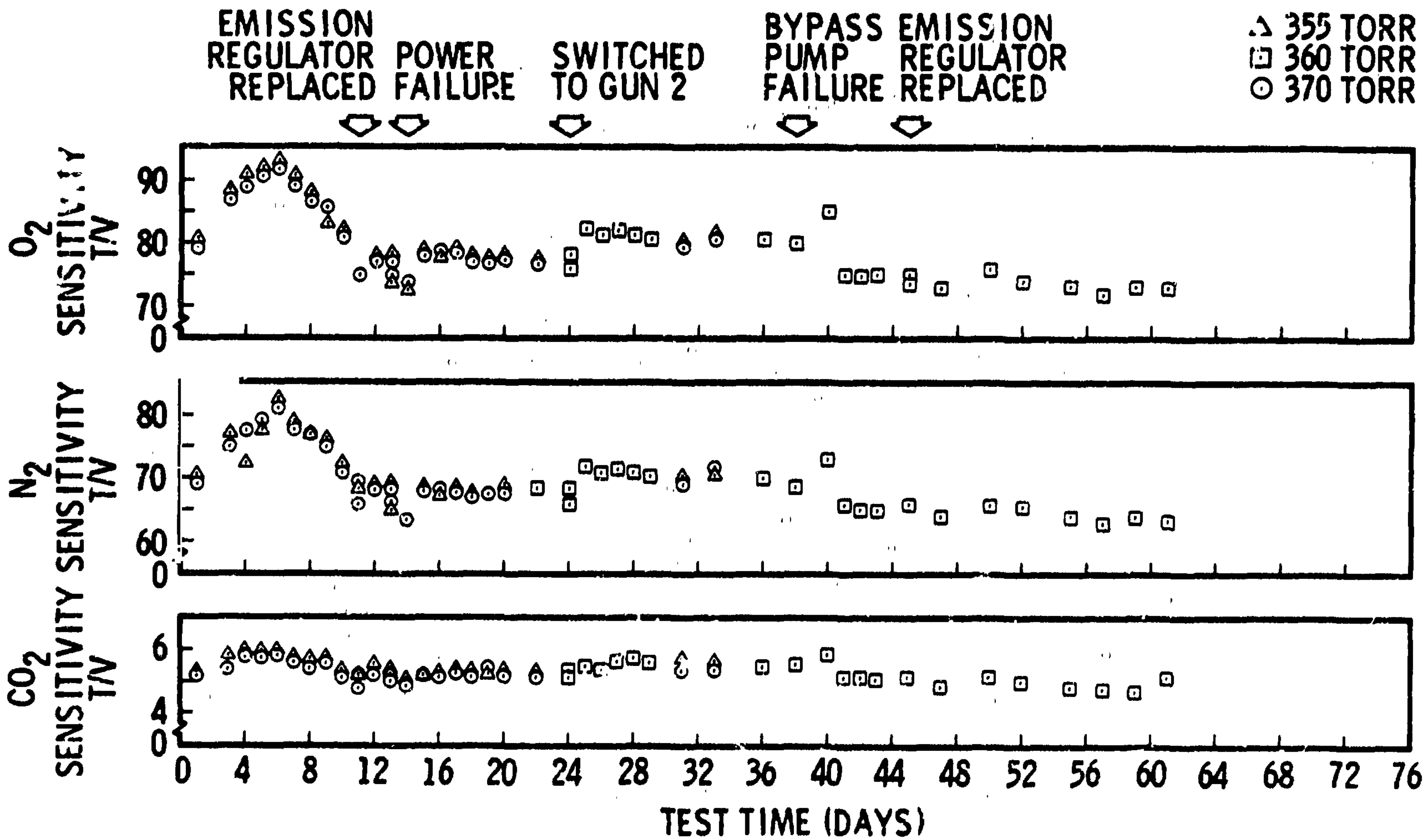


Figure 15. Sensitivity vs Time (Mass Spectrometer Sensor)

The variation in pressure over which the mass spectrometer was required to sense and control during the 60-day test can best be shown by using two typical days. A typical stable 24-hour period has been plotted on Figure 16, and a somewhat unstable 24-hour period is shown in Figure 17. These are typical days and do not necessarily represent the most stable or unstable periods during the 60-day test.

The differences between the mass spectrometer and the Beckman paramagnetic analyzer which cannot be attributed to previously mentioned problems are listed as follows:

1. Poor accuracy of the output meters for obtaining readings from the two-gas sensor.
2. Instrument output (as a function of time during the calibration period) responded in varying ways to chang in inlet pressure.
3. A few readings may have been taken before complete restabilization occurred after two short duration power failures.

Most of the causes for error have been noted with changes initiated by Perkin Elmer to render the mass spectrometer a very reliable and highly accurate sensor and controller. These changes will provide a compact unit which is capable of sensing and controlling several gases. A complete evaluation of the mass spectrometer is contained in Reference 9.

4.3 WATER MANAGEMENT

The water management system consisted of a potable water recovery subsystem, which recovered water from humidity and urine for crew consumption, and a wash water recovery subsystem which reclaimed used wash water to be used for personal hygiene only.

4.3.1 System Operation

The open-cycle air evaporation process was used to recover potable water from humidity and urine. The potable water recovery subsystem was divided into two functional sections:

1. Air Evaporation Section--Included the urine collection, treatment, and feed module; the urine evaporation module; and the water condensation-separation module.
2. Post-Treatment Section--Included the silver-ion generator, the filter module, the detoxification module, four thermal storage tanks, and a hot and cold water supply loop.

Wash water was recovered by a multifiltration process which included microbial filters, charcoal columns, ion-exchange resin columns, storage tankage, and hot wash water supply loop.

The potable water recovery subsystem operated successfully for the entire test period, with only minor unscheduled maintenance requirements. Potable water which met all National Academy of Sciences/National Research Council (NAS/NRC) standards (Reference 2) was produced from urine, humidity

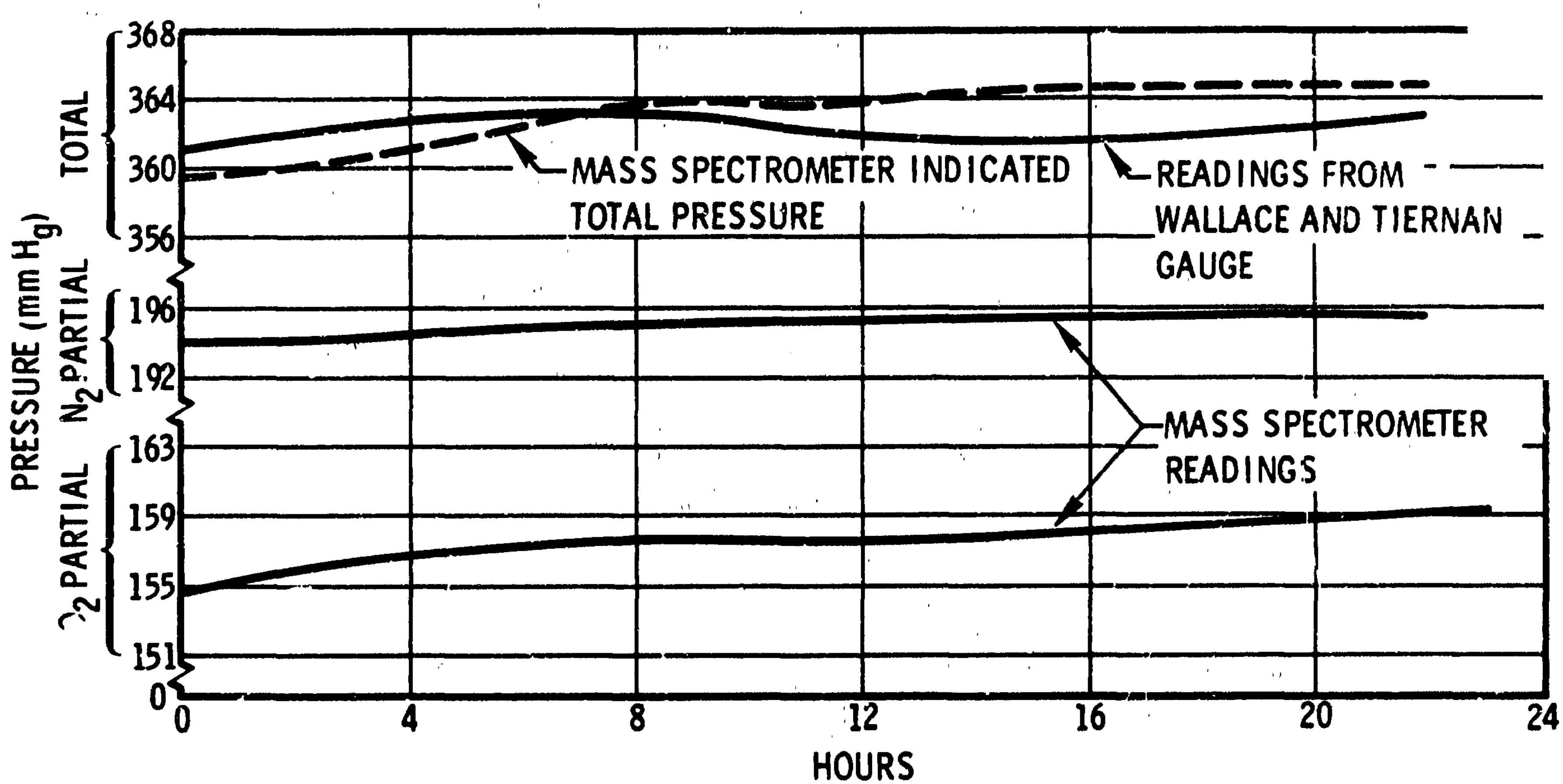


Figure 16. Pressure Variations During a Typical Stable 24-Hr. Period

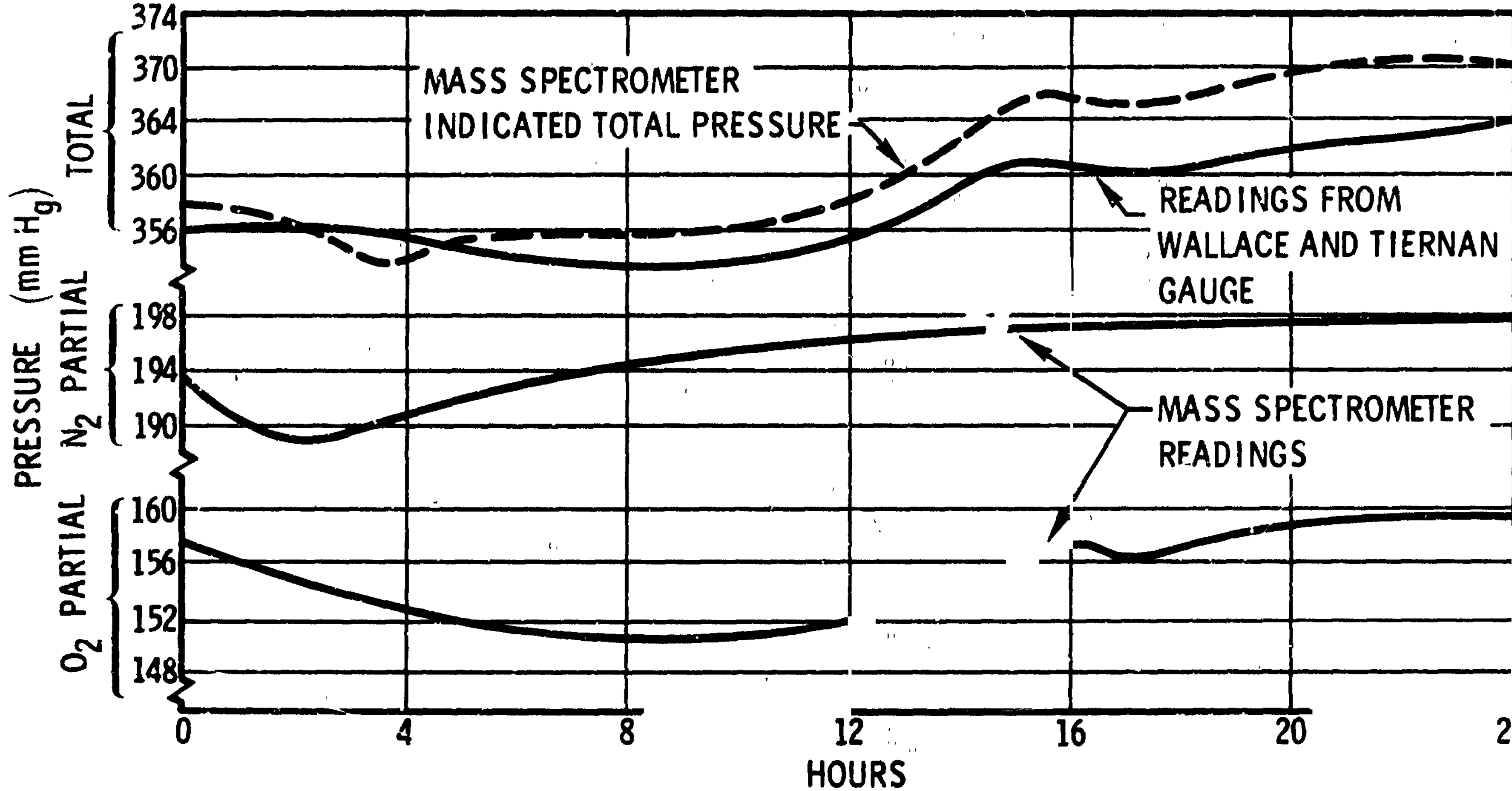


Figure 17. Pressure Variations During a Typical Unstable 24-Hr. Period

condensate, condensate from the thermal control heat exchanger, and condensed silica gel desorbate from the carbon dioxide removal subsystem, as shown in the mass balance, Figure 18. Initially, potable water was produced from all these sources. However, the test protocol required that only two of the crewmen would consume the reclaimed water and that the others would be consuming distilled water provided from an external source. Therefore, since the system was capable of providing water in excess of the needs of two men, the processing of the silica gel desorbate and thermal-conditioning heat exchanger condensate was discontinued on days 10 and 36, respectively (except for 39.6 lb of thermal control heat exchanger condensate, which was subsequently fed to the wick evaporator).

The data recorded by the crewmen show a total of 1,025 lb of potable water produced, of which 137 lb was extracted for chemical and microbiological analyses and 888 lb was available for crew consumption. The two crewman who were using reclaimed water recorded a consumption of 408 lb, and the remaining 480 lb of reclaimed water was discarded. The two control crewmen who were using outside distilled water recorded a consumption of 505 lb. The total amount of water consumed by the crew, according to their records, was 913 lb. If the 158.4 lb (300 ml/man-day) of anticipated metabolic water is added to this, the expected total water output would be 1,071.4 lb. This compares with a total recorded water output of 1,405.3 lb (919.6 lb of humidity water plus 485.7 lb of water contained in the 510 lb of urine). This large discrepancy is attributed primarily to errors in the manual recording of intake data by the crewmen. There is confidence in the reliability of the output data because electronically recorded urine feed data and manually recorded urine volumes agreed closely.

This water output data, reduced to an individual daily basis, is compared in Table 14 with water balance data from other chamber tests as reported in Reference 10, and indicates that the recorded output data are close to expected values.

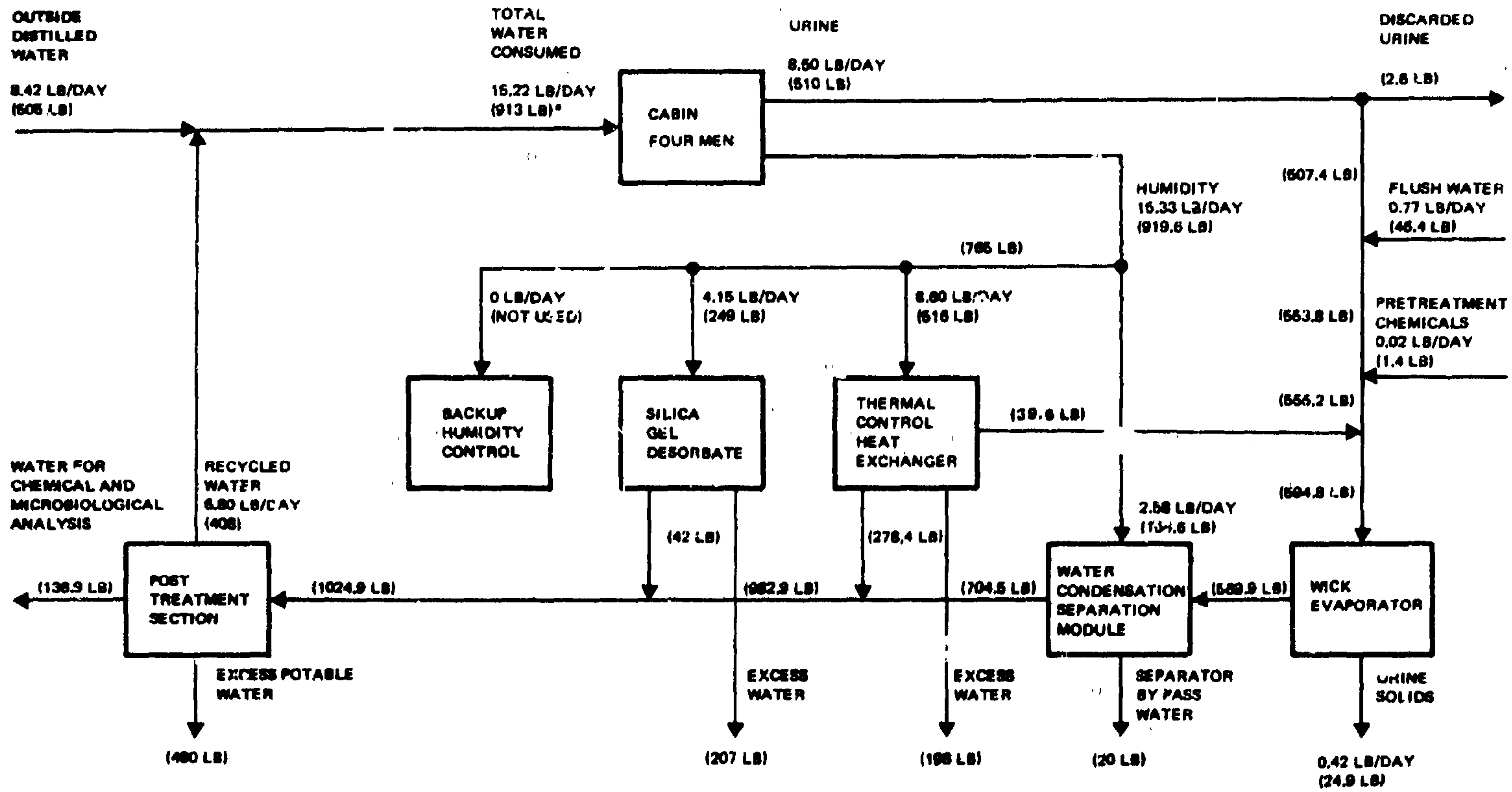
4.3.2 Air Evaporation Section

The Air Evaporation Section was designed for the simultaneous recovery of water from human perspiration, respiration, and urine. It provided for the collection and chemical pretreatment of urine and the controlled feeding of the pretreated urine to a wick evaporator from which it was evaporated into an air stream that was drawn from the cabin and discharged back to the cabin, and condensation of urine distillate together with cabin humidity. A schematic of the complete potable water recovery subsystem is shown in Figure 19. The installation in the SCS is shown in Figure 20.

4.3.2.1 Description of Equipment

The urine collection and feed module included the funnel, burette and valve, pretreatment liquid dispenser and dispenser chart, urine transfer/dump valve, urine transfer pump, flush water tank, valve and hose. All of these components can be seen in Figure 21.

1.0 ml of pretreatment fluid (sulfuric acid, chromium trioxide, and copper sulfate) was scheduled for addition to each 250 ml of urine. Flush water was used to cleanse the funnel and burette to prevent odors. With the burette valve open, the urine transfer pump was turned on to transfer the urine mixture from the burette through the 10μ and 3μ urine filters to the holding tank.



*NUMBERS IN PARENTHESES ARE TOTAL

Figure 18. Water Recovery Subsystem Mass Balance

Table 14

COMPARISON OF WATER INTAKE/OUTPUT DATA WITH OTHER TESTS

Temperature Deg. F	Relative Humidity Percent	TW Total Water (Output) ml	U Urine Output ml	IW Insensible Water ml	U/TW	Source of Data
73	Not Stated	2160	1164	953	0.54	Reference 10*
78	30	2660	940	1740	0.35	This Test**
90	40	3520	738	2702	0.21	Reference 10*

Note: *Reference 10, Experiment IX.

**Total water is from sum of urine and latent loss from Figure 18. If recorded input data are used, TW = 2.022 ml from this test.

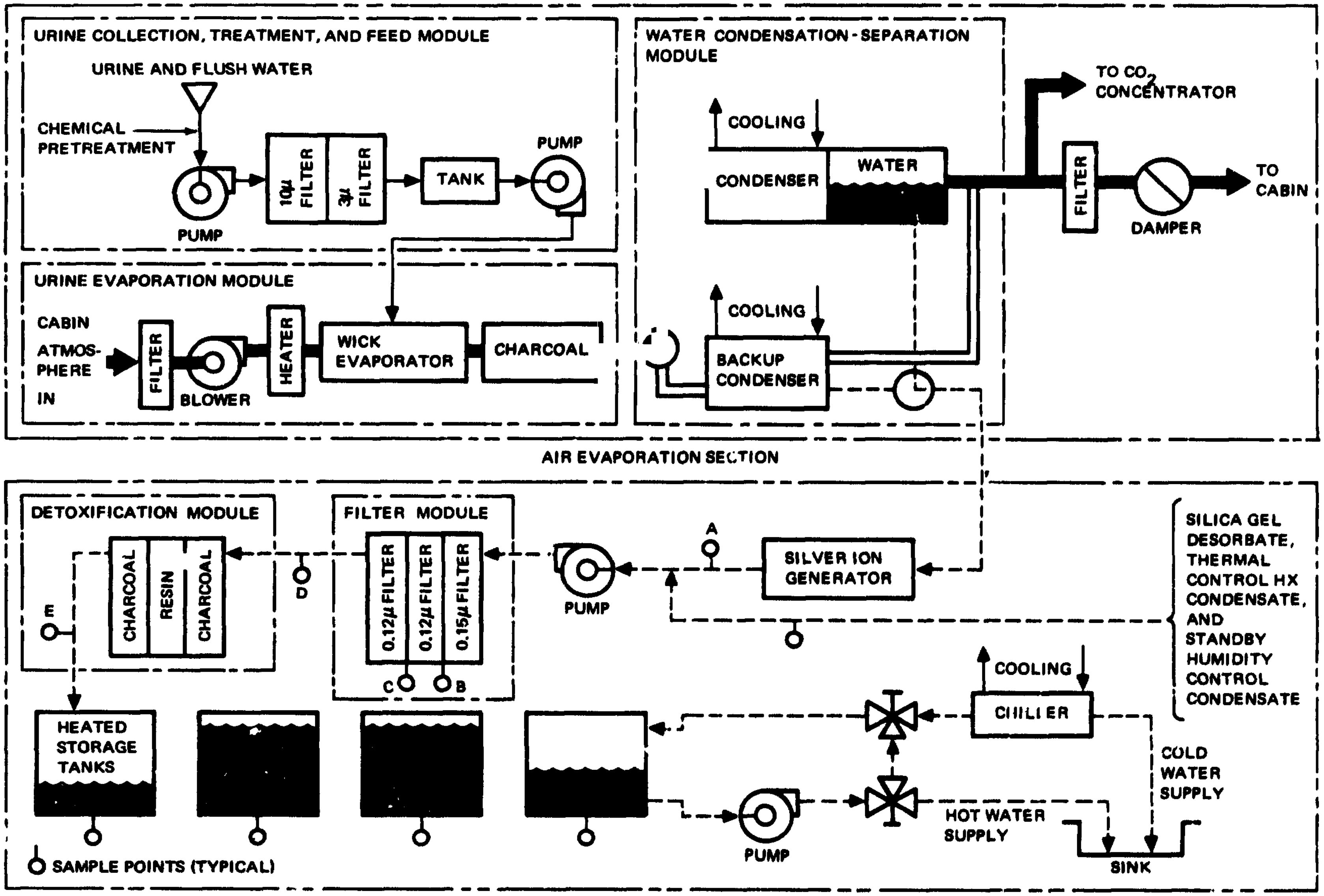


Figure 19. Potable Water Recovery Subsystem

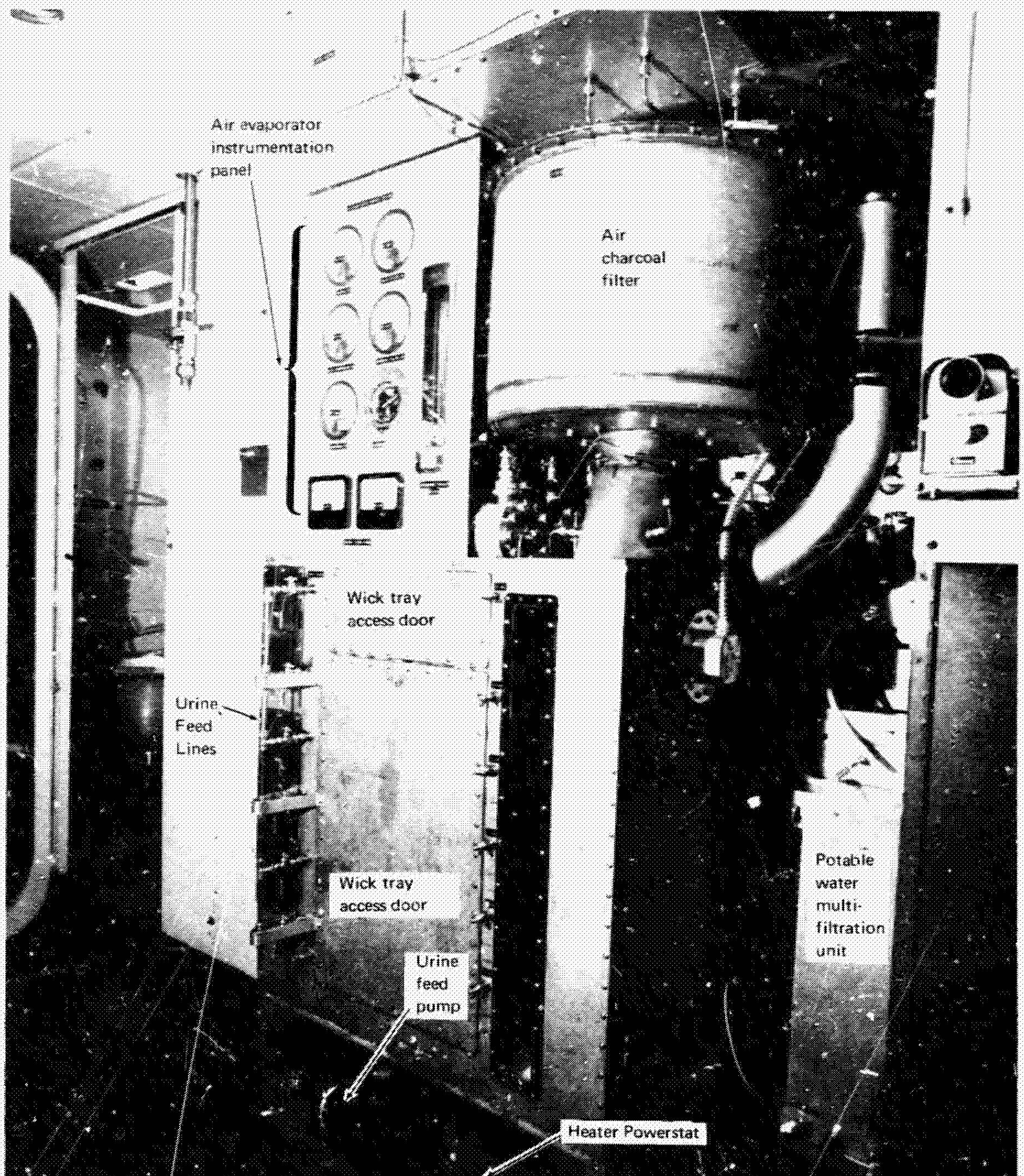


Figure 20. Open-Cycle Air Evaporation Section

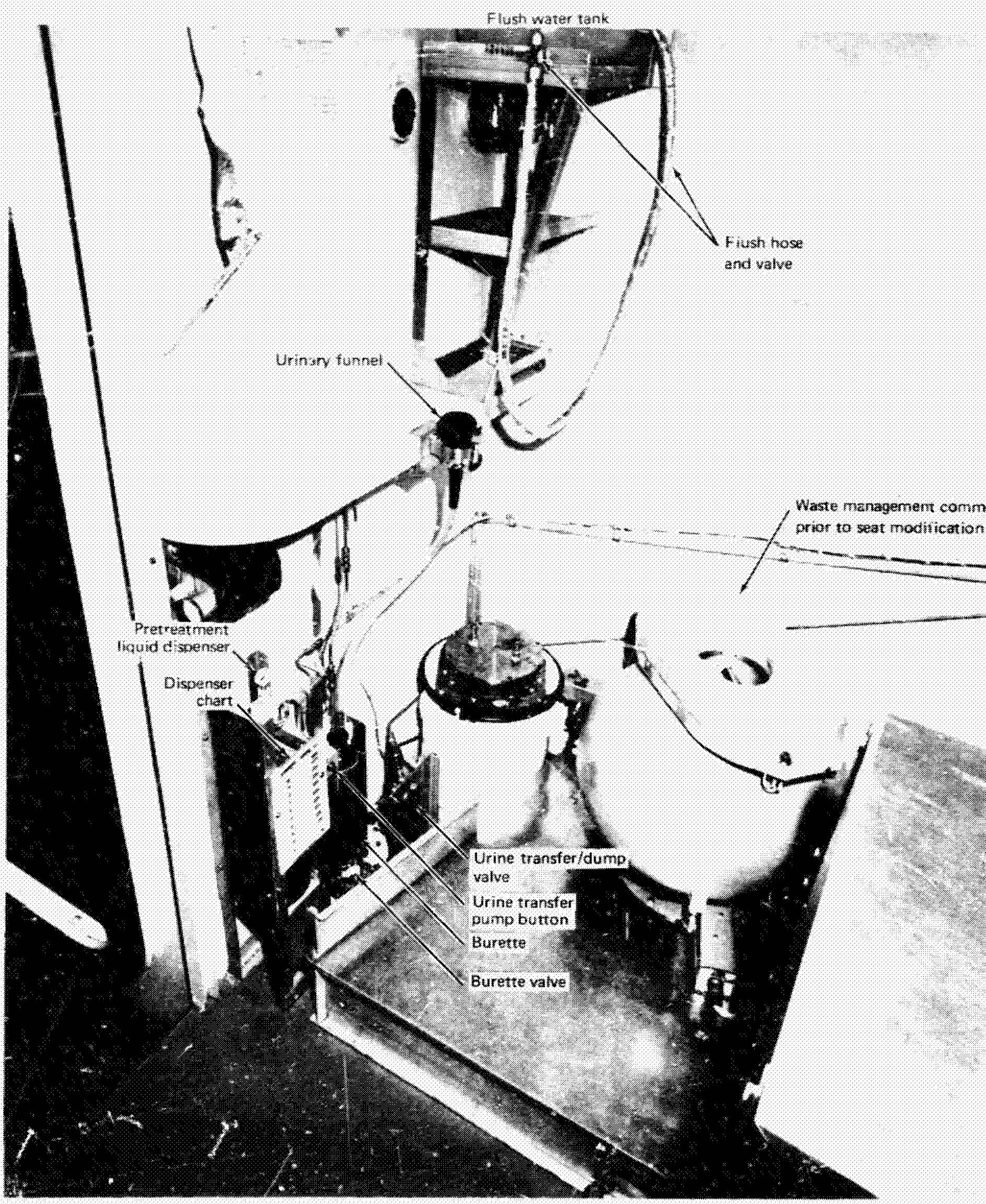


Figure 21. Installation of the Urine Collection, Treatment, and Feed Module

If required, the urine mixture could have been transferred into an overboard dump tank by moving the urine valve to the dump position prior to actuation. After transferring the urine mixture to the holding tank, the burette valve was closed. When 1, 000 ml of urine had collected in the holding tank, it was pumped to the wick section of the air evaporator by activation of the automatic electronic liquid level control.

The urine evaporation module included particulate air filters, a blower, a heater, a urine evaporation compartment that contained a bank of six wick evaporators, an air charcoal-filter, and associated ducting, valves, instrumentation and controls. The blower pulled air from the cabin through a 1μ filter and then forced it through the electric heater where the air temperature was raised to approximately 110°F. The heated air was then ducted through the one of six wick evaporator units into which urine was being fed and sensible heat from the air stream evaporated the water vapor from the urine in the wick elements. From the wick evaporator, the air passed through a charcoal filter that adsorbed cabin and urine odors, then through the water condensation-separation module that lowered the air temperature and absolute humidity and removed the condensed water droplets from the air. The dehumidified air was then discharged back to the cabin through another 1μ air filter. Two water condensation-separation modules were provided in parallel and valved for separate use. One was a simple plate and fin type condenser from which the condensate drained by gravity and was used only when the other (zero-g) water condenser/separator failed to operate or was down for inspection.

4.3.2.2 Zero-g Water Condenser/Separator

The zero-g water condenser/separator was furnished by NASA/LRC. This unit was adapted from the prototype humidity control system fabricated for NASA/LRC by Lockheed Missiles and Space Division under Contract No. NAS1-5622 (Reference 11).

The unit consisted of a condensing heat exchanger, a water separator, and a water transfer assembly. The installation of this unit as part of the Air Evaporation Section is shown in Figure 22. The water separator removes the water droplets from the gas stream on a conical hydrophobic screen that allows the cabin atmosphere to pass on through the unit and return to the cabin. The water droplets move to the base of the conical screen, collect, and flow into a sump that has three hydrophilic porous metal elements. These allow water to pass, but not the cabin atmosphere. Because the water production rate was sufficiently low, only one sump was used at a time.

The pressure difference across this hydrophilic sump controls the water transfer assembly. The transfer assembly consists of a pressure switch, a solenoid valve, and a pump. The water pressure difference across the sump actuates the pressure switch, which opens the solenoid valve and operates the transfer pump; this moves the water into the next part of the water recovery process. The unit was instrumented to measure coolant flow through the condenser, coolant inlet and outlet temperatures, condenser inlet gas temperature and dewpoint, condenser outlet gas temperature, water separator outlet gas temperature and dewpoint, and cabin atmosphere pressure difference through the condenser/separator unit.

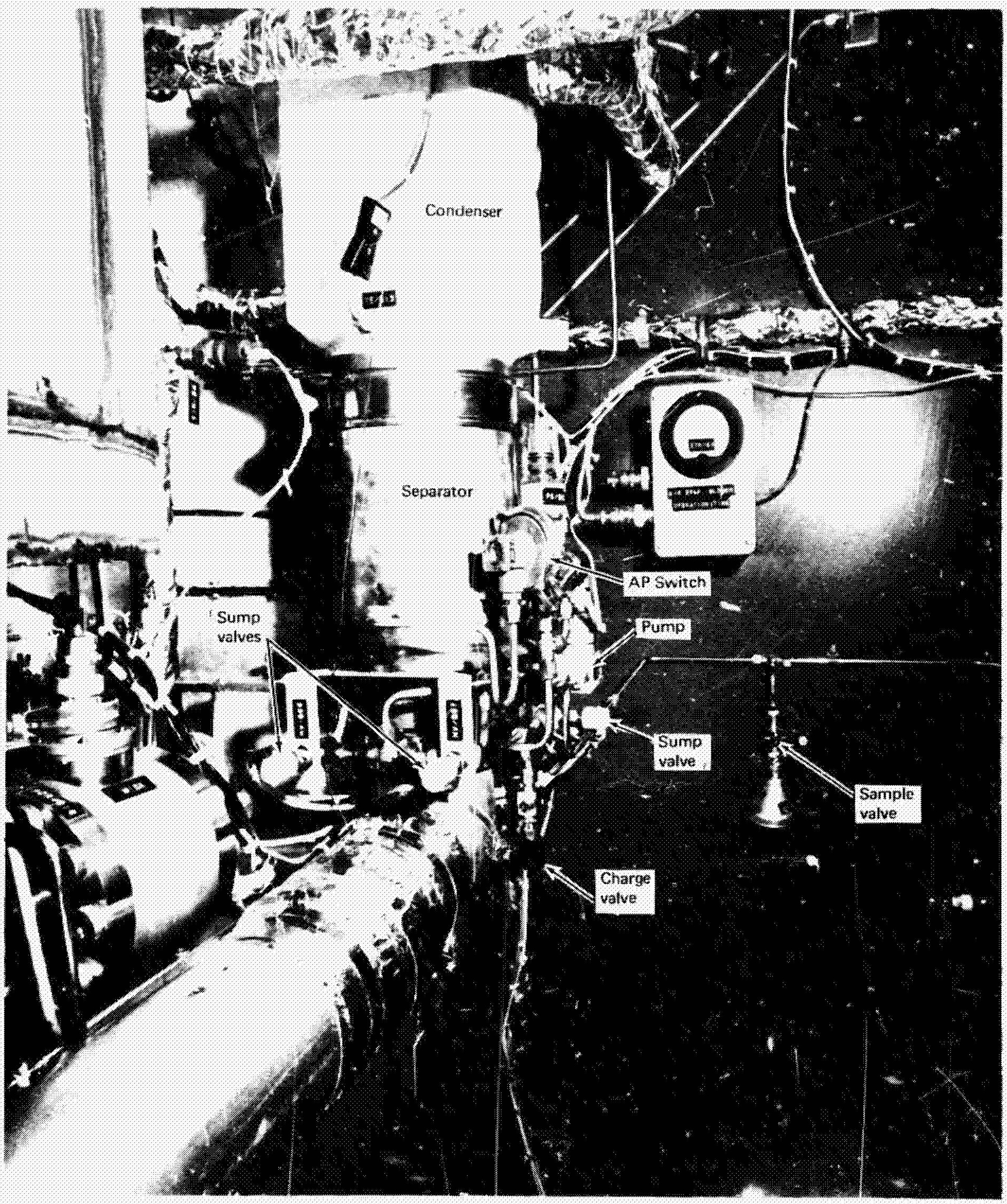


Figure 22. Zero-G Water Condenser/Separator Installation

4.3.2.3 Air Evaporation Section Performance

A total of 507 lb of urine (225 liters with an average density of 1.024 g/ml) were processed during the run. The record of wick usage is shown in Table 15. The nominal design life for each wick assembly was 10 days. Use of the first assembly was discontinued after 13 days, when the crew reported a slight odor of ammonia in the cabin. The second assembly lasted 17 days and the third assembly went for 20 days, at which time a noticeable ammonia level (17 ppm) was again reached. The 60-day run ended before the fourth wick assembly showed any sign of reaching the end of its useful life. During the previous bench tests, the wick life had surpassed the 100-liter mark, equivalent to about 25 days, but data obtained during this test are believed to be short of this value because an insufficient quantity of pretreatment chemicals was added to the urine. Although the schedule called for 4 ml of chemical pretreatment (39.8 percent H_2SO_4, 9.8 percent CrO_3, 47.3 percent H_2O, and 3.1 percent $CuSO_4$ per liter of urine) actual usage amounted to approximately 2 ml per liter. This shortage occurred because the dispenser failed to deliver the proper quantity.

Photographs of the disassembled wick evaporators are shown in Figures 23, 24, 25 and 26. The uneven distribution of urine solids (dark areas) is apparent. The light areas shown in the wick strips represent unused wick capacity that would be usable if proper distribution of urine were obtained.

In previous bench tests, a much more even distribution of solids was obtained. A combination of higher evaporation rates, lower amounts of urine than anticipated, and partial blocking of the urine feed pump inlet by mold that resulted in lower than normal pressure at the feed tube discharge orifices, may account for most of the uneven distribution, but the relative effects of various other factors on the solids distribution in wicks is largely unknown. More bench test experimentation with wick evaporators is required to gain the knowledge necessary to achieve even solids distribution, which gives better wick utilization and longer wick life.

Typical temperature and pressure drop values for the wick evaporator are shown in Table 16.

Table 15

SUMMARY OF WICK USAGE

Wick Package No.	Days Used	Urine Processed Liters	Total Urine Solids In Wick: Grams	Total Urine Solids In Wick: Grams/Liter	Weight of Urine Solids Per Weight of Wick Grams/Gram
1	13	52	2533	49	1.68
2	17	64	3192	50	2.11
3	20	70	3609	51.5	2.39
4	10	39	*	*	*

*Unable to determine because package not fully dried at end of run.

Table 16
TYPICAL TEMPERATURE AND PRESSURE DROP VALVES
FOR WICK EVAPORATOR

	Temperature °F		
	Maximum	Average	Minimum
Wick Inlet	123	111	101
Wick Outlet	110	95	86
Condenser-Separator Inlet	110	95	86
Condenser-Separator Outlet	42	38	33
Wick Inlet Dew Point	49	42	38
Condenser-Separator Inlet Dew Point	52	47	42.5
Condenser-Separator Outlet Dew Point	50	39	36.5
		Pressure Drop (In. H_2O) at Average 80 SCFM & 7.0 PSIA	
Inlet Air Filter		0.9	
Wick Package		0.9	
Air Charcoal Filter		0.6	
Condenser-Separator		0.65	

The average power consumption for the potable water recovery system was 1.127 kW, broken down as follows: blower--0.194 kW, air heaters--0.431 kW, and potable water tank heaters (four)--0.502 kW. The total power consumed does not include that required to run the four pumps in the system, of which only one operated continuously, but it is estimated that this power would not exceed an additional 28W.

The system required minimum maintenance during the test period. This maintenance consisted largely of minor sensitivity adjustments to the electronic liquid level controllers. The only unscheduled maintenance, besides that required on the zero-g water separator, was the removal of material, presumably mold, that plugged the inlet fitting to the wick urine feed pump on day 42 (Figure 27).

After completion of the 60-day test, inspection of the particulate filter, located in the urine line between the transfer pump and the feed pump, revealed about 100 grams of accumulated solids. This material consisted of normal urine constituents such as amorphous u rates phosphates, and mucus threads as well as fungus mycelium, predominately penicillium species. Photographs of these filters are shown in Figure 28.

The zero-g water separator was operated during the 5-day checkout run and processed water from both the cabin atmosphere and wick evaporator at 7 psia. Following this, the unit was operated 47 days during the 60-day run. During the first 21 days, no maintenance or repairs were required. Between days 21 and 23, the unit operated for some time with the solenoid valve open continuously and the pump running; the pressure switch was replaced on days 31 and 51. Two hydrophilic sumps were replaced on day 23 and all three on days 31 and 51. This replacement was done to clean the sump screens and to obtain samples of any material collected from the gas stream.

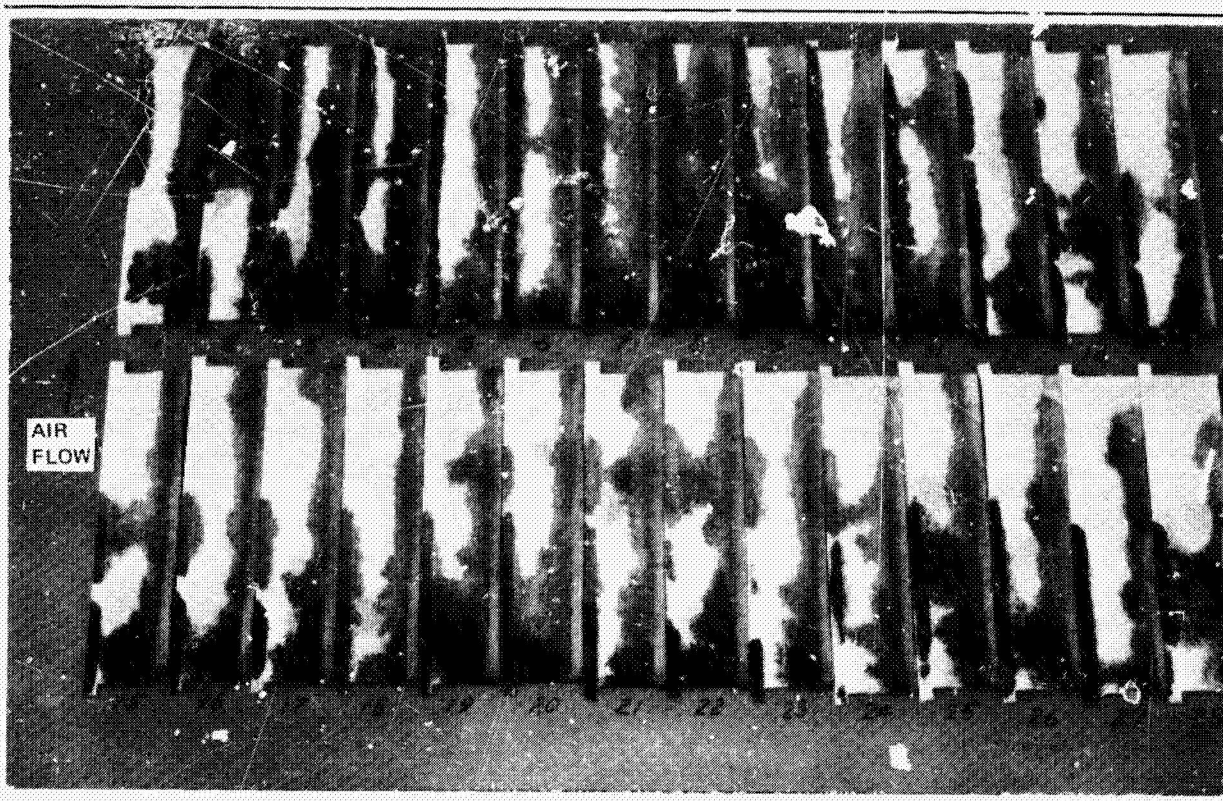


Figure 23. Disassembled Wick Evaporator No 1

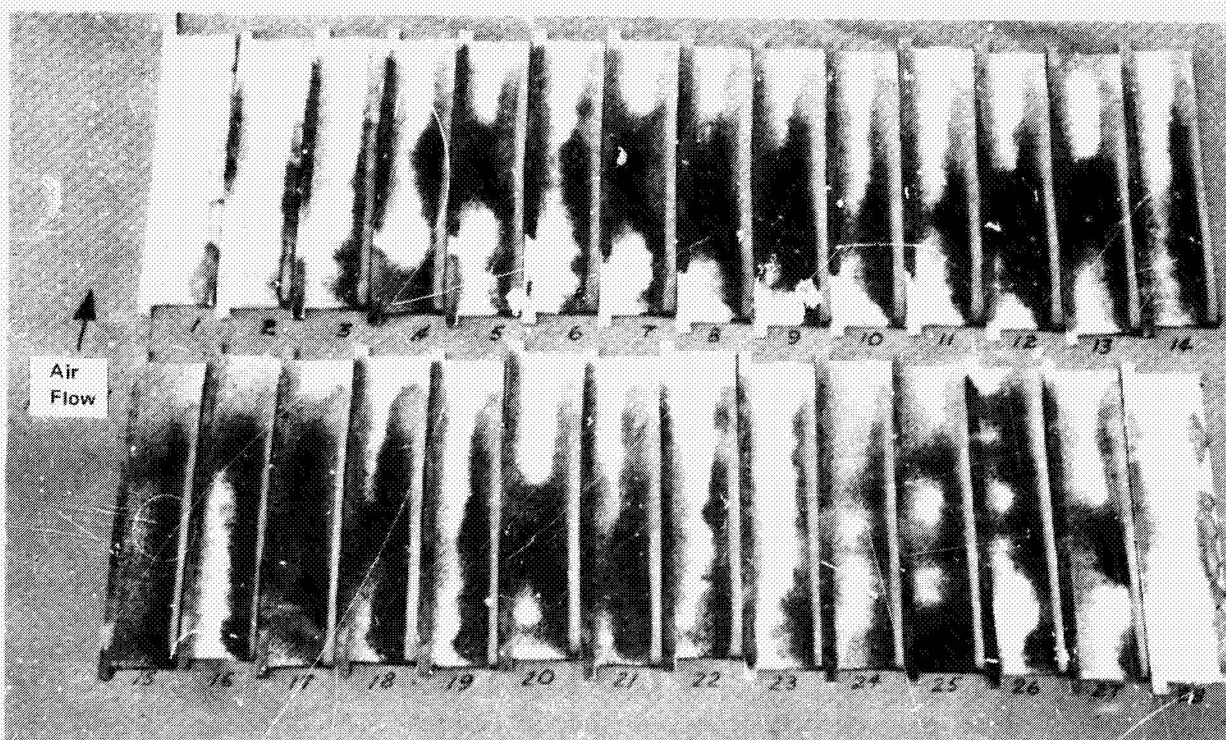


Figure 24. Disassembled Wick Evaporator No. 2

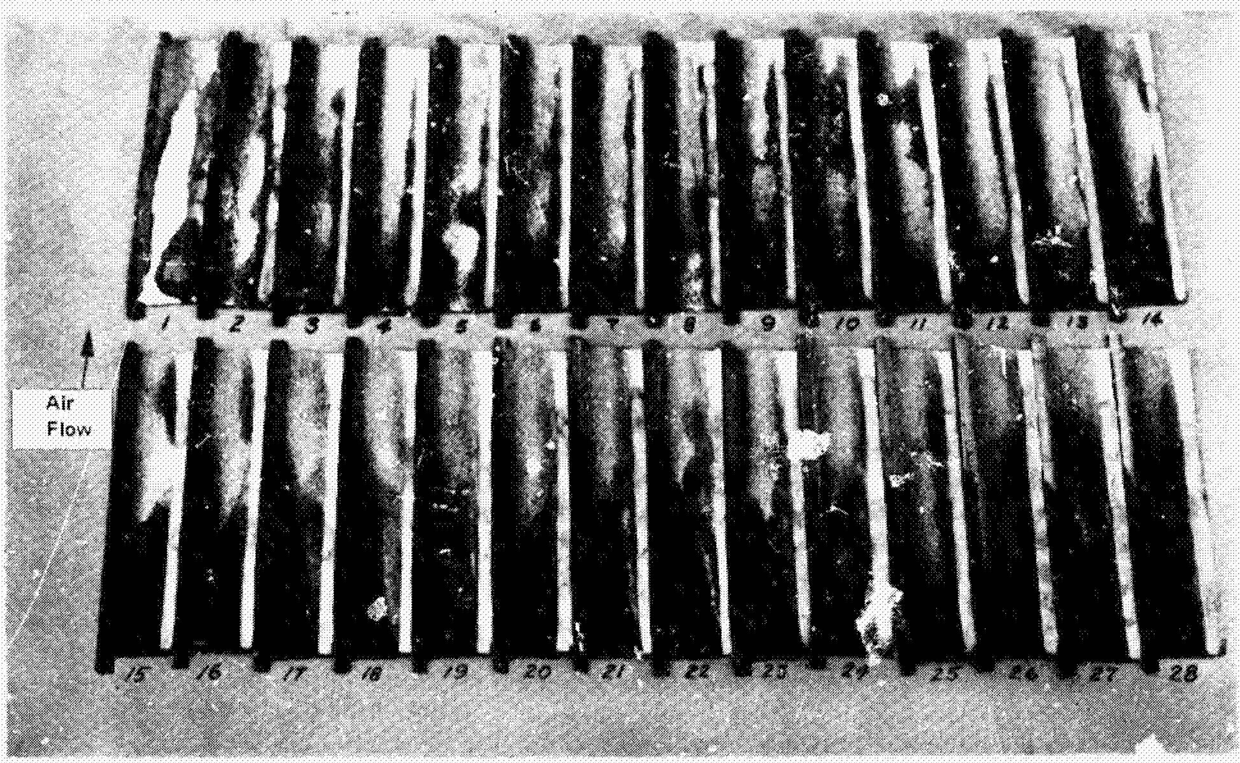


Figure 25. Disassembled Wick Evaporator No. 3

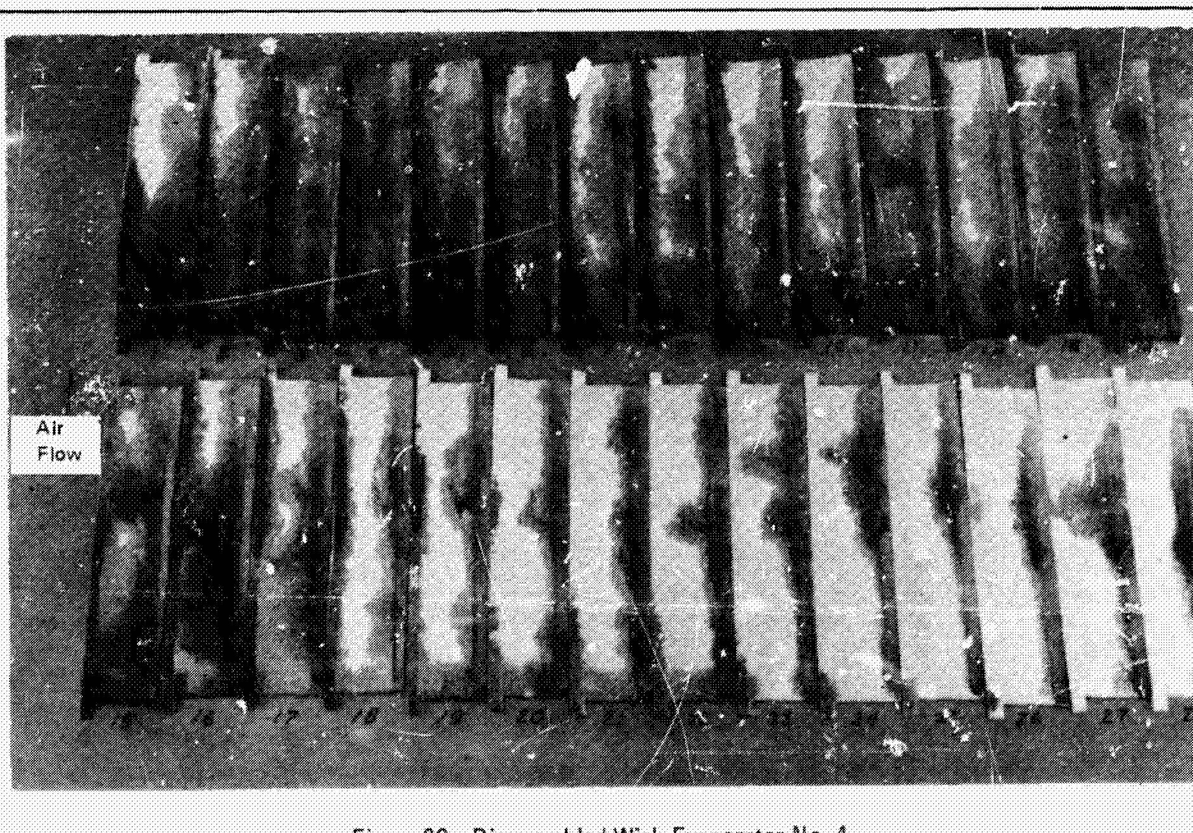


Figure 26. Disassembled Wick Evaporator No. 4

Figure 27. Blockage of Urine Pump Inlet Fitting

Figure 28. Urine Filters after 60-Day Test

Chemical analysis of water entering the Post-Treatment Section showed the presence of Coolanol 35, leading to consideration of the possibility or a coolant leak in the condenser. Therefore, the zero-g water condenser/ separator was not used for 13 days. During this period, the backup 1-g condenser was used while a spare zero-g unit was obtained and installed. No leakage was found when the suspected unit was pressure tested after removal and replacement.

Adjustment of the sump valve was necessary several times during the run to accommodate increased water production. The valve of the open hydrophilic sump was throttled with the intention of keeping the sump screens wet. When the water production rate exceeded the capacity of the valve adjustment, the water level rose above the sump and went through the hydrophobic screen, collecting in the duct downstream of the unit. Maintenance and adjustment were performed by the crew with verbal direction from outside personnel to correct this condition.

4.3.3 Post-Treatment Section

The Post-Treatment Section was designed for final polishing of reclaimed water including removel of trace organic and inorganic solutes, prevention of microbial growth, removal of microbes, and removal of potential microbial toxins. A schematic of this section is also shown in Figure 19. It was intended primarily for processing condensate from the Air Evaporation Section but was also used to purify silica gel desorbate and condensate from the thermal control heat exchanger. The standby humidity control condenser also discharged to the Posttreatment Section. This condenser was not used during the 60-day test, but would have been, had it become necessary to discontinue operation of the open-cycle air evaporation subsystem.

A condenser was installed in the carbon dioxide removal subsystem to catch the water vapor that was desorbed from the silica gel beds. This desorbed water vapor would have been discharged directly to the cabin atmosphere and subsequently recovered in the humidity control system. However, if this mode of operation had been used, condensation would have occurred in the air line leading to the air flowmeter, causing blockage of air flow in low segments of the line.

4.3.3.1 Description of Equipment

The Post-Treatment Section includes a filter module, a detoxification module, heated storage tanks, and a dispensing circuit. The filtration and detoxification modules were designed to treat the combined urine distillate and humidity condensate and achieve purity in accordance with the NAS/NRC-recommended standards (Reference 2). The filter unit and detoxification modules were separately removable for sterilization when necessary. Together, these modules included all of the plumbing between the condenser-separator and the thermal storage tanks. Sterility was maintained by periodically autoclaving the units when microbial contamination was detected. The filter module consisted of three Pall Corporation heavy-duty microbial filters with 0.12 to 0.15μ pore diameter. The detoxification module was composed of two charcoal columns and a single multipurpose ion-exchange column.

Water from the condensation-separation module was pumped first through the filtration module where microorganisms were removed, and then through the detoxification module where dissolved toxins and other chemical contaminants were removed by the adsorbents. The sterile effluent from the columns was pumped to one of four potable water thermal storage tanks.

The four thermal storage tanks were maintained continuously at pasteurization temperature (160°F) to inhibit the growth of microbial contamination. Any one of these tanks could be connected to the distribution circuit that continuously circulated hot water from the tank to the sink area and back to the tank. Two faucets at the sink provided for drawing either hot or cold water. The hot water was drawn directly from the circulating loop. The cold water was provided by drawing hot water from the loop through a chilling heat exchanger using Coolanol 35 as a heat sink.

Normally, of the four potable water storage tanks, one was being filled, one tank was being used, and the contents of two recently filled tanks were being evaluated for bacteriological and chemical purity. This evaluation required two days. Each water storage tank had a capacity of 35 liters, of which about 28 liters was available for use; the balance was required to keep the electrical heaters immersed. A calibrated sight gage was provided on each tank to obtain water production and usage data.

During the first 11 days of the test, a different multifiltration unit was used. It was similar in concept, but differed in design from the unit described above. Its filtration module was identical to the one described, but the detoxification module could not be disassembled for complete sterilization. Microbial contamination breakthrough on day 11 led to its abondonment and the adoption of the described unit, which was successfully used for the remaining 49 days of the test.

Since the test protocol required that only two of the subjects would consume the reclaimed water and that the other two would be controls, the control subjects consumed distilled water from the outside backup water facility. This backup water facility consisted of cold and hot water supplies piped into the cabin sink panel from outside the SCS. The backup cold water supply included a cold water tank, pump, filter, valves, sampling port, and a chilling heat exchanger. The backup hot water supply included a tank with a heater, pump, filter, valves and a sampling port.

4.3.3.2 Silver-Ion Generator

The silver-ion generator that was evaluated during the course of the SCS test was designed and manufactured by AiResearch Division of Garrett Corp. This water sterilization cell was developed by AiResearch for NASA to be used in the Apollo spacecraft water systems. It was evaluated in the SCS as an adjunct to microbial control in the potable water reclamation subsystem. An electrical schematic of this unit is shown in Figure 29.

The electrolytic silver-ion generator is an individual, self-contained unit which does not require external power, control, or maintenance after installation. The absence of interface requirements facilitated the installation of the unit within the existing potable water recovery subsystem downstream of the zero-g condenser/separator. The unit normally generates silver ions in concentrations of 50 parts per billion to more than 200 parts per billion in

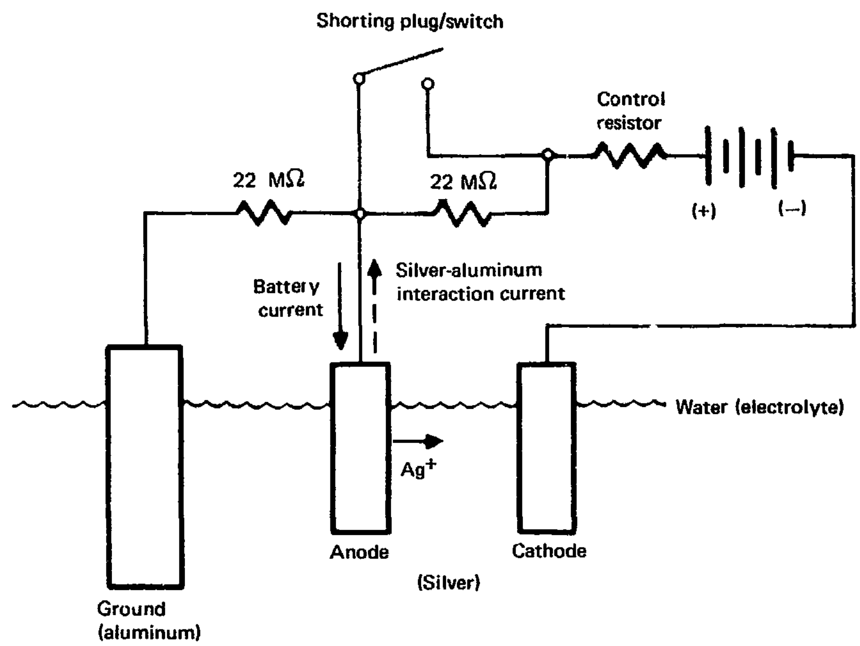


Figure 29. Circuit for Control of Current in Electrolytic Silver-Ion Generator

the water flow system. The desired concentration is achieved by selecting the proper loading resistor to match the average water flow rate. Static and dynamic tests indicate that these concentrations of silver ions are extremely effective in achieving a high kill rate of bateria and adequate bacteriological control. Ingestion of silver ions at these levels (50 to 200 parts per billion and higher) is not injurious to the crewmen. The concentration of silver ions in the SCS potable water subsystem was set at 200 parts per billion, based on a nominal water flow rate of 7 cc/min. The silver-ion generation rate is a function of the current, supplied by a self-contained battery and limited by the series resistor. Therefore, the silver-ion concentration varies inversely with the water flow rate.

Under no-flow or static water conditions, a self-limiting concentration is reached in the cell when the silver deposition or plating rate equals the silver-ion generating rate. Uniform concentrations and effective sterilization cannot be achieved in locations where rapid water surges exist, if the surge volume exceeds the cell volume and no mixing or diffusion occurs downstream.

The generator was 2.5 in. in diameter by 4 in. long and weighed about 0.6 lb. The component parts of the silver-ion generator included an aluminum housing with an internal volume of 3 cc designed to eliminate ion accumulation dead spots near the inlet and outlet ports; an anode of high-purity silver (to prevent introducing other metallic ions into the potable water stream); Teflon supports to center the anode and to provide the required water system distribution; a silver-plated aluminum cathode with insulation; a water inlet port; and a power supply system which included three resistors, a cathode lead, a silver anode lead positioned upstream of the cathode, a potted terminal board, a ground connection, and three 1.5-V silver oxide batteries with a probable life expectancy of 9,000 hours. For the SCS installation, a shorting plug was used as a switch to allow current to flow when the plug was in place and water was flowing through the unit. The silver-ion generator was designed for optimum performance with a constant water flow supply. The SCS potable water recovery subsystem yielded variations in flow rate estimated to be from 1.0 to 20 cc/min.

4.3.3.3 Chemical Analysis of Product Water

Chemical analyses of the product water were made on samples taken from various sampling ports throughout the system, or removed directly from the thermal storage tank. The NAS/NRC potability standards (Reference 2) were used as the guide for determining the potability of the water. The physical and chemical analyses of the three kinds of water (silica gel desorbate, thermal control heat exchanger condensate, and air evaporator condensate) that were fed to the Post-Treatment Section are presented in Table 17.

The silica gel desorbate met all NAS/NRC chemical standards except for COD = 184/100[1] mg/l and hexavalent chromium = 1.5/0.05 mg/l. There is no obvious explanation for the high Cr^{+6} level in silica gel desorbate. The thermal control heat exchanger condensate met all NAS/NRC chemical standards except for COD = 497/100 mg/l. The air evaporator condensate met all NAS/NRC chemical standards except for COD = 269/100 mg/l. When the COD contributed by ethanol is subtracted from this total, the new adjusted value is COD = 40/100 mg/l, which is well below the NAS/NRC recommended maximum value.

A summary of analyses done on storage tank samples is presented in Table 18, which also includes the NAS/NRC-recommended maximum values for comparison. Testing for halogens was not included in these analyses because previous developmental testing had indicated that maximum levels of chlorides or flourides were at least three orders of magnitude below the allowable maxima. Halogens were, therefore, not considered to be a potential hazard. Table 19 shows the individual COD values as well as the additional testing that was done routinely on all tank samples. In those cases listed, where the COD was above the allowable level of 100, further evaluation indicated that the major portion of the observed values was due to ethanol. Although that water was actually potable, it was discarded because of strict adherence to the NAS/NRC standards.

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[1] The number ahead of the slash refers to the measured value. The number after the slash is the NAS/NRC-recommended maximum value.

Table 17

ANALYSIS OF SPACE CHAMBER WATERS PRIOR TO POST-TREATMENT PROCESSING (TYPICAL VALUES)

Item*	Silica Gel Desorbate	Thermal Control Heat Exchanger Condensate	Air Evaporator Condensate
Turbidity (Jackson Units)	4	NT**	NT
Color (Platinum - Cobalt Units)	34	NT	NT
pH	8.	8.4	8.3
Specific Conductivity (μMHO-CM^{-1})	374	690	770
Total Solids	22.8	18.6	2.1
Ammonia	NT	106	110
Chemical Oxygen Demand	184	497	269
Ethanol	NT	82	118
2 Ethyl Butanol	NT	17	0.6
Total Aldehydes	NT	NT	1.7
Aluminum	0.34	0.14	0.02
Arsenic	0.0	0.0	0.0
Barium	0.0	0.0	0.0
Beryllium	0.0	0.0	0.0
Bismuth	0.0	0.0	0.0
Boron	0.05	0.15	0.01
Cadmium	0.0	0.0	0.0
Calcium	0.11	0.19	0.02
Chloride	0.0	0.0	0.0
Chromium (Cr^{+6})	1.5	0.0	0.0
Cobalt	0.0	0.0	0.0
Copper	0.11	0.14	0.02
Fluoride	0.0	0.0	0.0
Iron	0.02	0.15	0.0
Lead	0.0	0.0	0.0
Lithium	0.0	0.0	0.0
Magnesium	0.14	0.11	0.002
Manganese	0.003	0.09	0.0002
Mercury	0.0	0.0	0.0
Nickel	0.0	0.0	0.0
Potassium	0.0	0.0	0.0
Selenium	0.0	0.0	0.0
Silicon	1.6	0.19	0.2
Silver	0.0	0.0	0.0
Sulfate	0.0	0.0	0.0
Sodium	0.0	0.0	0.0
Tin	0.02	0.0	0.0
Zinc	0.0	0.09	0.0

*All values in mg/l unless otherwise noted.
**NT = not tested.

Table 18

SUMMARY OF POTABLE WATER ANALYSES: STORAGE TANK SAMPLES

	Mean Observed Value	Maximum Observed Value	NAS/NRC-Recommended Maximum Values
I. Physical Standards			
Turbidity (Jackson Units)	2.1	5	<10
Color (Plat.-Cobalt Units)	3.8	5	<15
Taste	None		None objectionable
Odor	None		None objectionable
Foaming	None		None persistent more than 15 sec
pH	7.2	6.3 to 8.7	N.E.*
Specific Conductivity (μmho-cm^{-1})	36	420	N.E.
II. Chemical Standards (in mg/liter)			
Ammonia	4.8	12.5	N.E.
COD	77.1	166.0	100.0
Aluminum	0.28	0.46	N.E.
Arsenic	0.0	0.0	0.5
Barium	0.0	0.0	2.0
Beryllium	0.0	0.0	N.E.
Bismuth	0.0	0.0	N.E.
Boron	0.91	2.32	5.0
Cadmium	0.0	0.0	N.E.
Calcium	1.97	4.64	N.E.
Chloride	N.T.†	N.T.	450.0
Chromium (Cr^{+6})	<0.001	0.002	0.05
Cobalt	0.0	0.0	N.E.
Copper	0.32	0.49	3.0
Fluoride	N.T.	N.T.	2.0
Iron	0.06	0.16	N.E.
Lead	0.0	0.0	0.2
Lithium	0.0	0.0	N.E.
Magnesium	0.65	0.90	N.E.
Manganese	0.18	0.36	N.E.
Mercury	0.0	0.0	N.E.
Nickel	0.17	0.23	N.E.
Potassium	0.21	0.21	N.E.
Selenium	0.0	0.0	0.05
Silicon	3.05	4.64	N.E.

Table 18 (page 2 of 2)

	Mean Observed Value	Maximum Observed Value	NAS/NRC - Recommended Maximum Values
Silver	0.01	0.02	0.5
Sulfate	0.0	0.0	250.0
Sodium	0.68	0.90	N.E.
Tin	0.0	0.0	N.E.
Zinc	2.2	2.2	N.E.

*No established value.
†Not tested (see text).

Table 19

PHYSICAL PROPERTIES AND CHEMICAL ANALYSES OF POTABLE WATER: TANK SAMPLES

Test Day	Tank No.	Color	Turbidity As S_iO_2	pH	Spec Cond. $\mu mho\text{-}cm^{-1}$	COD	Cr^{+6}
T2	2	0	2	6.5	<4	14	0
T4	3	0	2	6.5	4	15	0
T5	1	0	0	6.5	0.5	41	0
T11	3	<5	2	6.3	<5	74	0
T14	4	5	2	6.6	61	149	0
T19	4	0	<2	7.0	28	110	0
T22	2	<5	2	6.7	14.5	165	0
T24	1	<5	0	6.9	22	47.8	0
T28	1	5	2	6.3	35.5	69.8	0.0005
T28	3	5	4	7.05	112	90	0.002
T34	2	<5	2	6.5	22	166	0
T34	3	<5	2	8.7	340	63	0
T38	1	<5	1	8.5	420	87.7	0
T42	2	<5	2	7.4	86	64.5	0
T43	3	5	4	8.6	175	58.8	0
T49	2	<5	5	8.1	96	53	0
T52	2	<5	2	8.5	146	52.5	0
Potability Limits	-	<15	<10	-	-	100	0.05

4.3.3.4 Microbial Analysis of Product Water

To verify sterility throughout the multifilter unit and in the thermal storage tanks, water samples were taken from a series of sample ports at regular intervals and examined for evidence of microbial contamination. For these assays, samples of approximately 10 ml were withdrawn from the sample ports into sterile test tubes, using aseptic precautions. Each of the sample ports was fitted with an inverted funnel that acted as an automatic centering device and protected the port from extraneous contamination. Samples withdrawn were mixed well, and 1 ml aliquots were pour-plated with molten Trypticase Soy agar for incubation at 37°C. These plates were normallyenumerated at 24 and 48 hours although on frequent occasions they were held for periods of up to 7 days. The longer incubation time never yielded any significant additional growth. Selected results from these tests are shown in Table 20.

During design testing, the potable water recovery subsystem had been uniformly refractory to the passage of viruses. Furthermore, no viruses were expected to multiply within the system. For these reasons, and because the water was stored at 160°F for a minimum of 48 hours before it was consumed, the routine culturing for cytopathic viruses was not believed to be necessary. Similarly, routine culturing for anaerobic species was not performed on a regular basis.

Of particular importance among the daily samples were those removed from ports B, C, and D shown on Figure 19. Operationally, when bacterial contamination was detected at site B, the filter unit was removed and resterilized by autoclaving. An interesting point noted quite consistently throughout the test was that, when contamination was detectable beyond one filter, it rapidly penetrated the additional barriers (C and D) as well. For this reason, the degree of protection afforded by multiple filters did not prove to be as great as had been initially hoped. In practice, it was assumed that if microorganisms were detected at sample point B they had gained entrance to the charcoal and ion-exchange columns. These columns were, therefore, resterilized as well. To maintain sterility within the reclamation system, it was necessary to change or resterilize the barrier filters a total of 14 times during the 60-day period. The columns were changed or resterilized eight times, although actual contamination was demonstrated only on six occasions.

As indicated in the descriptive section, water that reached the storage tanks was maintained continuously at 160°F. This temperature was chosen to effect pasteurization and to ensure thermal inactivation of viruses. A theoretical objection to this procedure was that the continued high temperature might select in favor of thermophilic bacteria or actinomycetes, but no problems of this nature were encountered. Thermal storage, therefore, appears to be an acceptable way to maintain the sterility of stored water.

On one occasion, on day 37, samples from Tank 1 indicated contamination. During the evaluation of this problem, it was discovered that the temperature of the tank was lower than planned (138°F), because of an erroneous setting of the tank thermostat. This setting was corrected and an attempt was made to clean the sample port by draining several liters of the heated water. This proved successful and there were no further problems. Although it is probable that the contents of the tank were actually never contaminated, but only appeared so because of a contaminated sample port, safely indicated that the tank be declared nonpotable. Normally, one of the thermal storage tanks containing certified water was held in reserve for use in such situations; however, this tank had been erroneously discarded by the crew. This necessitated the crew's use of "backup water" for a 3-day period until a new supply could be chemically and biologically certified, thereby interfering with an otherwise unbroken record of reclaimed water consumption.

Another point of interest in Table 20 is the variation in bacterial count downstream of the condenser separator. F · the first 22 days of the test, the counts obtained from samples were essentially zero, possibly due to operation of the silver-ion generator immediately upstream of the sample port. The generator was disconnected on day 21, and after that time the bacterial count rapidly increased at that site. The count remained elevated until day 45, when it dropped to zero and remained at zero for the duration of the test. On day 51, the silver-ion generator was reconnected. There is no obvious explanation for the zero bacterial counts between days 45 and 51.

In evaluating the silver-ion generator, the operating protocol called for enumerating bacteria in the water stream at points close to and at some distance from the silver-ion source. Data so obtained were then compared with similar data obtained during the period in which the ion generator was removed from the system. During this operation, the concentration of silver ions was determined at intervals by emission spectrograph analysis of water samples drawn from various points in the system. It was of particular interest to determine whether the ion exchange columns effectively removed the silver as expected. The concentrations of silver provided by the unit are shown in Table 21 as determined by semi-quantitative data obtained by emission spectroscopy.

The erratic concentrations observed may have been due, in part, to the sampling procedure itself, since silver ions are quite readily adsorbed by glass surfaces. The concentration of silver in the samples taken downstream of the ion-exchange column increased steadily with the passage of time, despite the fact that the ion-exchange resin was replaced during the period in question. This suggests that the rise in concentration downstream of the exchange column was not simply due to a "loading" of the column's capacity to remove ionic silver. An untested hypothesis offered in explanation is that some constituent of the water was capable of reducing the silver ions to metallic silver, which could then pass through the exchange resins. If a chemical reduction of ionic silver occurs, then an insignificant killing efficiency would have been expected, because metallic silver does not have the bacteriostatic or bactericidal properties of the ionized form.

Table 20

POTABLE WATER MULTIFILTER MODULE

AVERAGE BACTERIAL TITERS (NO. CELLS/ML) AT SELECTED SAMPLE SITES

TEST DAY:	2	3	4	5	7	8	9	10	11	12	14	15	16	17	18	19	21
Filter Inlet (A)	0	0	0	0	0	2	1	0	2	0	0	0	0	0	0	0	-
Filter Outlet (B)	0	0	0	10^5	0	0	10^3	10^5	10^5	1	1	0	0	10^4	0	0	10^4
Column Outlet (E)	1	0	0	0	0	1	0	0	0	0	0	-	-	-	-	-	-
Tank No. 1	3	0	-	0	-	-	-	0	0	0	0	0	-	-	-	-	-
Tank No. 2	0	0	-	0	-*	-*	-*	0*	0*	1*	0*	0	-	-	-	-	-
Tank No. 3	0	0	-	0	-	-	-	0	0	0	0	0*	-*	0*	0*	0*	-*
Tank No. 4	3*	1*	-*	0*	-	-	-	-	-	0	0	-	-	0	0	0	-

TEST DAY:	22	23	24	25	26	28	29	30	31	32	33	35	36	37	38	39	40**
Filter Inlet (A)	0	200	10^4	10^3	140	10^5	10^3	10^4	10^3	10^3	10^3	10^3	10^3	10^3	10^3	10^3	20
Filter Outlet (B)	10^4	180	10^5	10^5	0	10^5	0	160	10^5	10^3	10^5	0	-	10^3	10^4	10^5	0
Column Outlet (E)	-	-	0	0	3	10^5	0	0	10^3	7	0	10^5	0	10^3	10^4	10^4	0
Tank No. 1	0	0	0	0*	0*	-*	-	-	-	-	0	0	0	10^3	10^4	0	10^3
Tank No. 2	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0
Tank No. 3	0*	0*	-*	-	-	-	0	0	0	0	0	0	-	-	-	-	-
Tank No. 4	0	0	0	0	0	-	0*	0*	0*	0*	0*	0*	0*	0*	0*	-*	-

TEST DAY:	42**	43**	44	45	46	47	49	50	51	52	53	54	56	57	58	59
Filter Inlet (A)	10^3	10^3	10^3	0	0	0	0	0	0	0	0	0	0	0	0	25
Filter Outlet (B)	10^4	10^4	0	0	0	10^3	0	0	0	0	0	0	1	0	3	5
Column Outlet (E)	0	10^4	0	0	0	40	10^5	10^4	0	0	0	15	10^3	10^3	10^4	10^4
Tank No. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tank No. 2	0	0	0	0	0	0	0	0	0	0	0*	0*	0*	0*	0*	0*
Tank No. 3	-		0	-	0	0	0*	0*	0*	0*	-	-	-	-	-	0
Tank No. 4	-	0	0*	0*	0*	0*	-	-	-	-	0	0	0	0	0	0

* Tank being consumed
** Crew drinking backup water supply

Table 21

SILVER CONCENTRATIONS IN THE POTABLE WATER SUBSYSTEM
(SILVER EXPRESSED IN PARTS PER BILLION)

	Downstream of Ion Generator	Before Ion-Exchange Resin Column	After Ion-Exchange Resin Column
Day 5	5	120	4
Day 9	150	50	20
Day 11	50	50	150
Day 15	270	270	180
Day 17	150	90	200

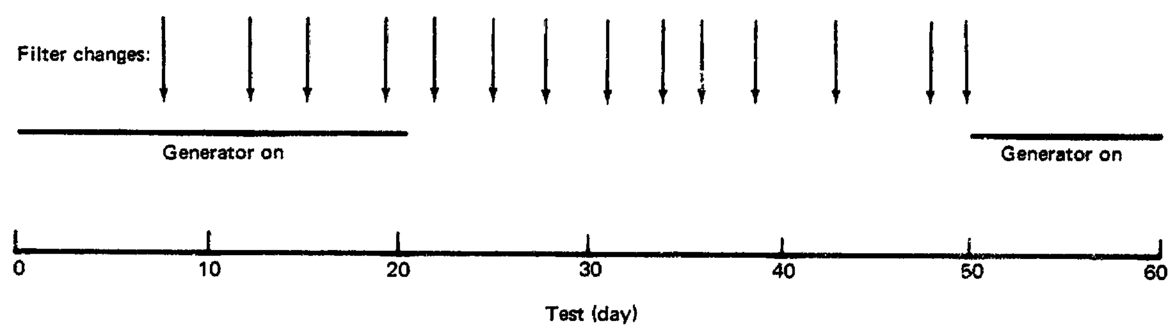
In actual operation, the unit was on-line for the first 21 days of the test. It was then disconnected for the next 29 days, and reinstalled for the last 10 days of operation. The bacterial data immediately downstream of the generator uniformly demonstrated that the unit was indeed effective in inhibiting bacterial growth at that part of the system. It was evident, however, that bacterial growth was not significantly inhibited further downstream. This may have been due to plating-out of the silver ions on metal surfaces within the system, to simple dilution of the ion concentration below effective levels by large variations in water production rate, or to reduction of the ionic silver to metallic form by some constituent of the water, as mentioned above. In any event, the unit did not produce complete sterilization of the water; microbe counts of up to 10^5 per ml were observed at various points in the system.

A different kind of estimate of the ion generator's efficiency can be obtained indirectly by examining the mean time between filter changes during system operation with the generator in use as compared with the off-line situation. In this case, one assumes that prolongation of filter life was attributable to the adjunctive effect of the silver ions. Figure 30 presents a summary of these calculations as well as a time-line diagram of the filter changes that were made. Viewed in this manner, it appears that the silver ion generator did contribute to longer filter life, and it was, therefore, effective to some degree even in the configuration used.

4.3.4 Wash Water Recovery and Waste Water Disposal

4.3.4.1 Description of Equipment

The wash water recovery subsystem consisted of a multifiltration unit with three circulating pumps, three charcoal columns, two ion-exchange resin columns, 13 bacterial filters, an ultraviolet light, a processing tank, and a hot water storage tank. The water from the wash water recovery subsystem was used for personal hygiene purposes only. A schematic diagram of the wash water recovery subsystem is shown in Figure 31, and in Figure 32 the multifiltration unit installation is shown.



	Average filter life
Generator on 31 days – 5 filter changes	6.2 days
Generator off 29 days – 9 filter changes	3.2 days
Longest time between changes: generator on	10 days
Longest time between changes: generator off	4 days

Figure 30. Silver-Ion Generator Operation

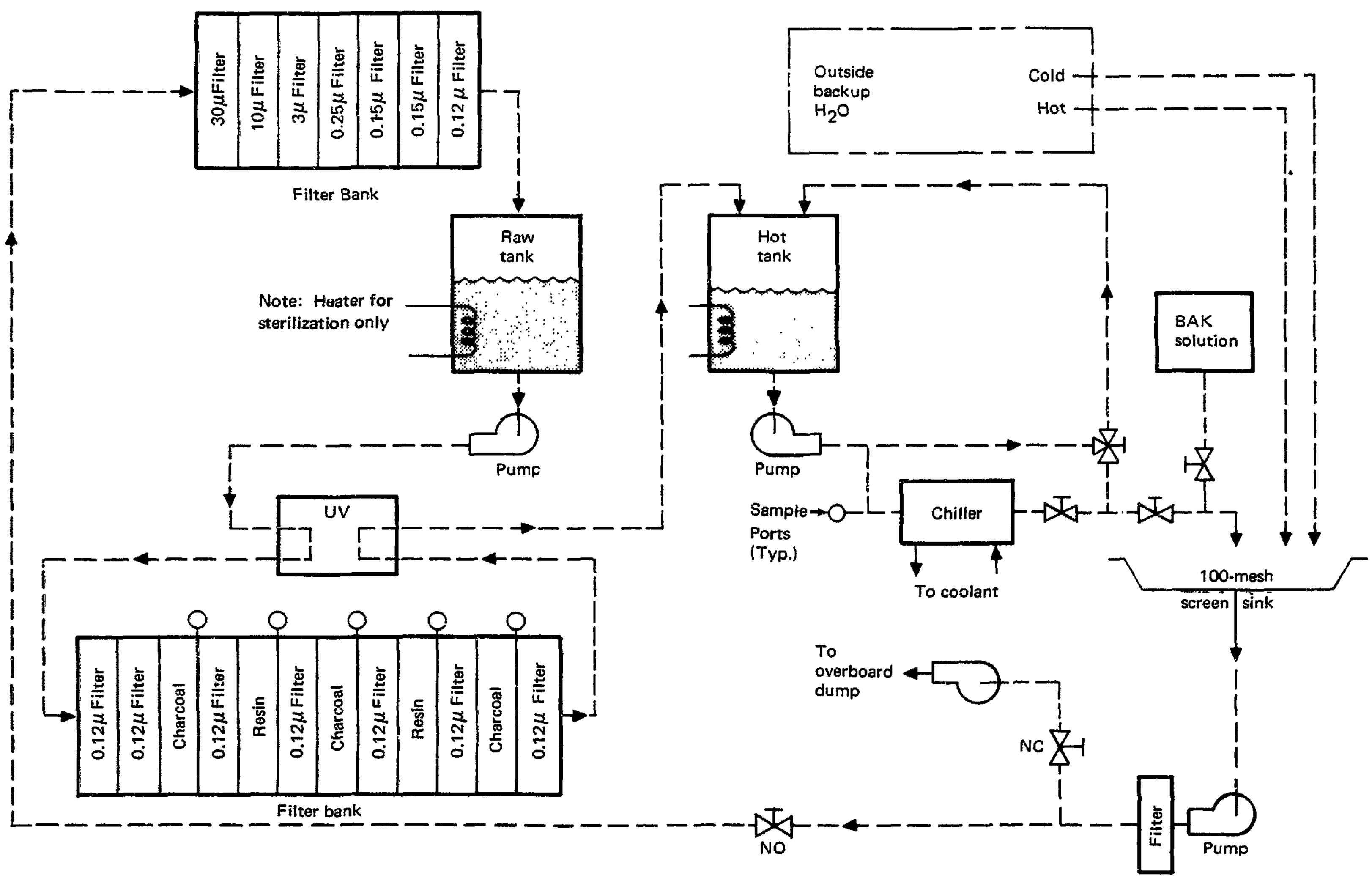


Figure 31. Wash Water Recovery Subsystem

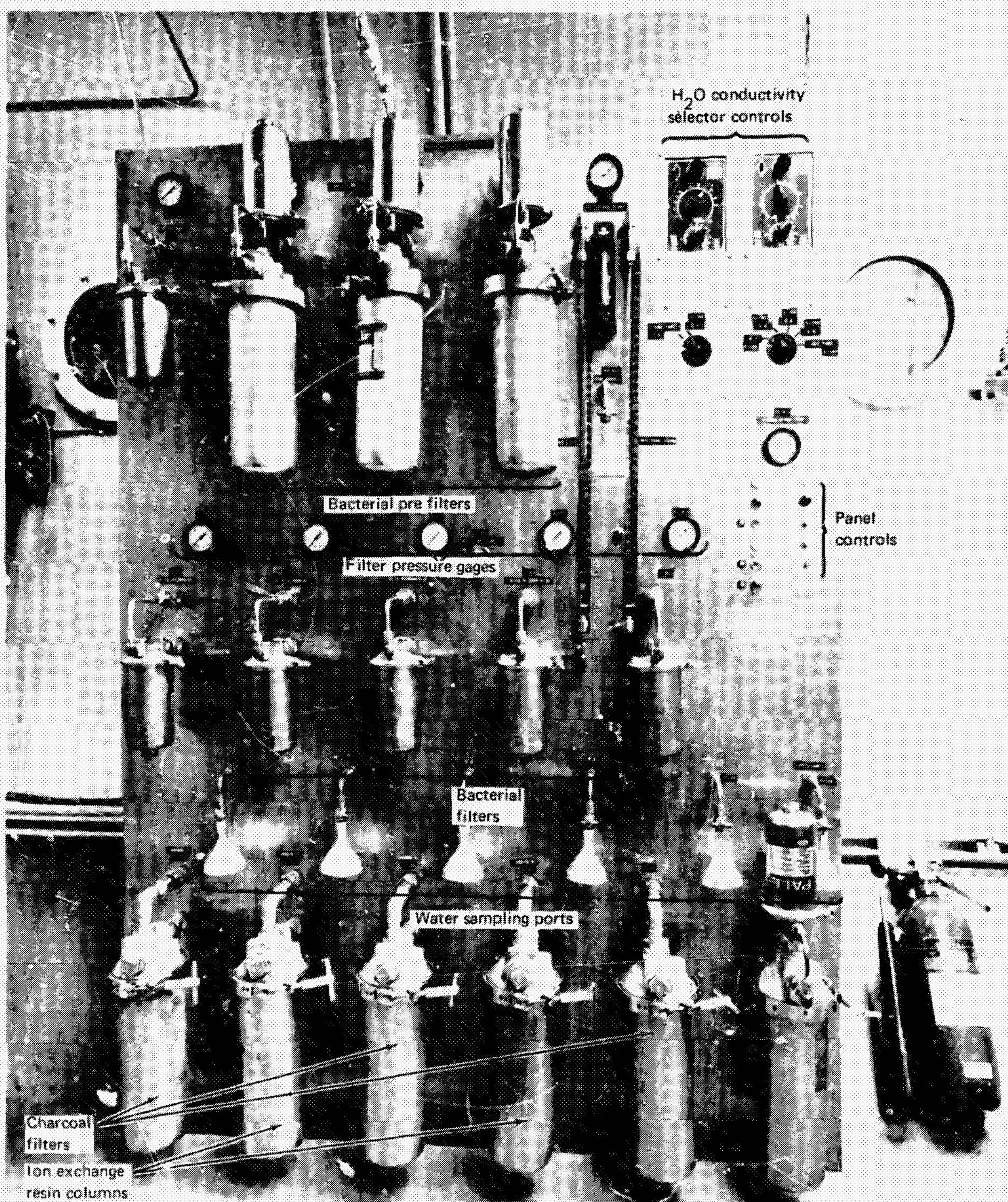


Figure 32. Wash Water Multifiltration Unit

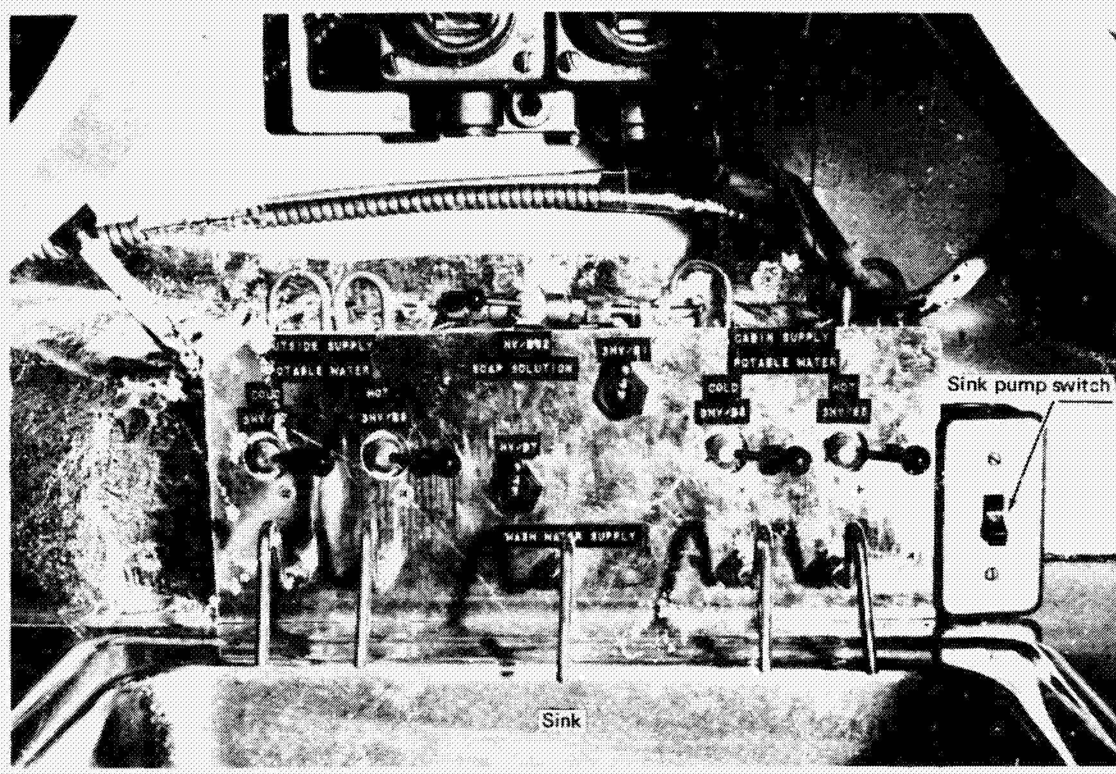


Figure 33. SCS Sink Water Control Panel

The purposes of the wash water multifiltration unit were to remove the total solids and to reduce the chemical impurities of the used wash and waste water from the cabin sink before the water was used again for washing.

The multifiltration unit received recently used wash water from the cabin sink with benzalkonium chloride (BAK) soap solution, and waste water containing food ingredients and miscellaneous particles. The water passed from the sink through a particle strainer and seven bacterial filters, and then passed into the raw collection tank. The water from the raw tank was pumped through the ultraviolet light and a series of bacterial filters, charcoal and ion-exchange resin columns, and into the hot storage tank. Ions of chloride and calcium salts, as well as other ionic species, were removed by these resin columns. The water in this storage tank, having been purified, was maintained at 150°F and was continuously circulated by a pump through a closed loop to the sink and back to the tank to be used as required. The circulation of hot water through the lines to the sink inhibited microbial growth in these areas. The wash water was cooled as desired at the sink outlet by the use of a Coolanol 35 heat exchanger in the delivery line.

At daily intervals, samples of the wash water were taken from the sample ports shown on the schematic and passed out of the cabin for microbiological profile analysis. Conductivity measurements were obtained from instrumentation contained within the subsystem. The conductivity sensors were located in the raw tank, at five points along the circulation flow path of the water through the filter columns, and at the hot tank. These conductivity measurements were monitored daily to provide performance data on the system. The urea, pH, organic nitrogen, and COD values of the samples were determined and a check on the water conductivity was made three times each week to monitor the accuracy of the subsystem conductivity measurements.

Within the SCS, the potable water, wash water, and backup supply is dispensed from the sink panel as shown in Figure 33. The sink panel provides a water outlet and a manual flow control valve for the outside hot and cold supply, and for the internal hot and cold potable water sources. The wash water supply has a single water outlet and two toggle valves that control the flow and temperature of wash water through the outlet. A valve at the top center of the sink panel controls the flow of BAK solution from the 5-gal BAK reservoir to the wash wateroutlet. BAK solution and wash water for rinsing are dispensed through the same outlet.

A storage tank was located in the waste management area and was used to collect liquids and mixtures which were not to be reclaimed by the water recovery subsystems. Liquids added to this dump tank were from the following three sources:

1. Mixtures of urine, pretreatment fluid, and flush water from the urinary burette when the potable water recovery subsystem was not operating. A three-way valve permitted the urine mixture to be diverted from the wick evaporator unit to the dump tank during the pumping operation.
2. Water from the condensate tank when the post-treatment section was not operating. A three-way manual valve was opened and the pump was actuated to allow this water to be pumped to the dump tank rather than to the potable water multifiltration unit.
3. Liquid mixtures from the cabin sink when the wash water recovery subsystem was not operating. The mixtures included liquid food, water with partially dissolved food particles, water that did not pass the potability tests, and liquids including contaminants such as Coolanol 35.

When the tank was nearly filled, as indicated by a sight gage, the contents were pumped into a sewer line outside the SCS. When the momentary pump actuation switch was closed to transfer the tank contents overboard, the pump energized and built up the pressure in the line, the pressure switch caused a pneumatic valve to open and the stored water was pumped out to the sewer. When this button was released, the pump would de-energize, the line pressure would decrease and, after a time delay, the pneumatic valve would close, leaving water in the line between the tank and the pneumatic valve. This prevented water and outside air from flowing into the tank.

4.3.4.2 Subsystem Performance

Microbial control in the wash water recovery subsystem depended on the combined effectiveness of microbial filters manufactured by the Pall Filter Corporation, a surfactant, benzalkonium chloride (BAK) at a concentration of 500 ppm, and an in-line ultraviolet disinfecting unit. During laboratory bench-testing of the development unit, sterility was maintained for more than 30 days despite repeated challenge with bacterial loads. The operational unit was installed in the SCS in the same configuration as the development unit; only a loop return from the processed water tank to the sink was added. This unit was designed to reclaim water from four men at the rate of 1500 ml/man/day. Following its installation, steam sterilization was accomplished in place by using the storage tanks and heaters as steam generators.

For the first 4 days of the test, the microbial counts of all samples were essentially zero. On the fifth day, however, the sink outlet and the heated tank sample ports showed contamination in the return loop, suggesting that this loop had not been completely sterilized. The receiving tank also showed contamination, apparently caused by a filter failure. Dilution resulting from greater than anticipated water usage and by coprecipitation with food particles caused the BAK concentration to fall below the design value of 500 ppm. This important adjunct to microbial control was thus depreciated, allowing additional microbial growth.

Stricter control of subsystem use by the crew eliminated many of these problems, but by that time, significant internal contamination had occurred. This gradually progressed throughout the system until day 25. On day 46, a general cleanup was attempted and the entire unit was flushed with hot BAK. This resulted in a significant inhibition of bacterial growth in the main system for 3 days, and for 12 days in the hot water circulating loop.

During the entire period of operation, the charcoal and resin columns continued to remove the bulk of organic and inorganic materials, as indicated by conductivity measurements. Samples from the second ion-exchange resin column, for example, never showed a conductivity in excess of 6μ mhos/cm. It would appear, therefore, that feasibility of the basic subsystem design was proved during the 60-day test period. Among the significant factors demonstrated were the possibility of maintaining a system free of back-contamination through microbial sampling ports and the ability to achieve in-place sterilization. An evident problem is the need to prolong microbial filter effectiveness, and additional means should be sought to control organic loading.

4.4 ATMOSPHERE PURIFICATION AND CONTROL

This system consisted of the carbon dioxide concentrator and toxin control subsystems, and was designed to remove the carbon dioxide, carbon monoxide and other trace contaminants which were generated within the cabin.

4.4.1 System Operation

4.4.1.1 Description of System

The carbon dioxide concentration in the cabin was controlled by the carbon dioxide concentrator subsystem which operated by selective adsorption principles, and delivered the carbon dioxide to an accumulator for processing by the Sabatier reactor.

The concentrations of carbon monoxide and other trace contaminants were controlled by the toxin control subsystem. In addition, some trace contaminant and odor control was provided by the charcoal filter in the potable water recovery subsystem and by the silica gel and molecular sieve beds in the carbon dioxide concentrator.

4.4.1.2 Contaminant Monitoring Procedures

It is by now recognized that the continuous inhalation of certain air pollutants present inside a space cabin may have harmful effects on the crew members, depending on the nature, quantity, and toxicity of the individual trace contaminants involved. This made it mandatory to identify and determine quantitatively, at frequent intervals, all contaminants present or likely to be present in the space cabin atmosphere.

A daily search procedure was therefore instituted in which representative air samples were withdrawn from the space cabin and analyzed. Sampling and analytical procedures depended on whether the tests pertained to organic or inorganic compounds. Levels of the more significant contaminants detected during the 60-day test are given in Table 22, together with principle methods analysis and predetermined alert levels (Reference 12).

Continuous monitoring of carbon monoxide, carbon dioxide, and total hydrocarbons was provided by infrared analyzers in the Gas Analyzer Console. Instrumentation was also provided within the console for continuous monitoring of the oxygen partial pressure and humidity of each gas sample. These analyzers provided sampling from any one of 24 locations within the simulator.

In view of the high sensitivity of the instrumentation, only small sample sizes were required to test for organic compounds. Samples of cabin gas of approximately 50 ml were collected by the syringe and needle method and injected into three gas chromatographs equipped with flame ionization detectors. The columns of each instrument were packed with different substrates; they consisted of didecyl phthalate, carbowax 1450, and apiezou. The three chromatographs had been calibrated prior to the 60-day run for 80 different contaminants,

Table 22

ATMOSPHERIC CONTAMINANTS IN SPACE CABIN SIMULATOR

Contaminant	Method of Analysis	Accuracy	Abort Level, 7 psia	Test Results Normal	Test Results Maximum
CO (ppm)	MSA, Lira Infrared Analyzer	±2.0	100.0	17.0	35.0
CO_2 (mm Hg)	MSA, Lira Infrared Analyzer	±0.4	12.0	4.0	7.25
Hydrocarbons (ppm)	MSA, Lira Infrared Analyzer	±2.0	400.0	5.0	35.0
NH_3 (ppm)	Nesslerization	±1.0	100.0	6.3	17.4
Aldehydes (ppm)	Absorption in Bisulfite Sln.	±0.05	20.0	0.34	0.89
SO_2 (ppm)	Sod. Tetrachloro-mercurate-p-rosaniline	±0.25	10.0	0.05	0.2
H_2S (ppm)	Cd. Sulfate-amine Sulfuric Acid Reaction	±1.0	20.0	0.0	0.0
$(NO)_x$ (ppm NO_2)	Saltzman Reaction	±0.1	10.0	0.11	0.7
O_3 (ppm)	Alkaline Iodide Method	±0.2	0.2	0.0	0.0
Chlorine (ppm)	O-Tolidine Reaction	±0.04	2.0	0.0	0.0
Cyanides (ppm)	Palladium Chelate Reaction	±1.0	20.0	0.0	0.0
Phosgene (ppm)	Test Paper Treated with Indicator	±0.2	2.0	0.0	0.0
Ethanol (ppm)	Gas Chromatography, Flame Detector Carbowax Column	±0.2	200.0	3.5	8.0
Toluene (ppm)	Gas Chromatography, Flame Detector Carbowax Column	±0.2	10.0	0.15	0.5
2-Ethyl Butanol (ppm)	Gas Chromatography, Flame Detector Carbowax Column	±0.2	40.0	1.2	3.5

by establishing the elution times of each probable contaminant for two temperatures. Agreement of the observed elution time of an unknown with the calibrated elution times of known compounds was considered as evidence of their identity. Whenever further confirmation was needed, large volume samples were concentrated in freeze-out traps at liquid nitrogen temperature. These samples were then analyzed by mass spectrometry and infrared spectophotometry.

Three chromatograms typical for the contaminant conditions during the 60-day run are shown in Figure 34. The first two chromatograms on the upper portion of the graph were obtained with 5-ml gas samples from normal space cabin air. Contaminants present in the cabin atmosphere immediately before the subjects entered are shown in the dashed-line chromatogram. The solid-line chromatogram was taken during the course of the run. The third chromatogram represents a sample of material condensed in a freeze out trap at liquid nitrogen temperature from 20 liters of cabin air.

The gas chromatographic analyses showed the presence of three principal contaminants; namely, ethanol, toluene, and two-ethyl butanol. The ethanol concentration in the cabin air ranged from 0.4 to 8.0 ppm. It had not been detected in previous runs. Its presence in the 60-day run appears to have been caused by the use of benzakonium-chloride, (BAK), a cleansing agent with germicidal properties that contains ethanol as an inert ingredient. BAK is recirculated in the wash water recovery system and is in frequent contact with the cabin atmosphere in locations such as the hot wash water tank and sink, where fresh BAK is mixed with reclaimed water.

Toluene was present in the cabin atmosphere in relatively low concentrations, ranging from 0.02 to 0.5 ppm. It may have been used as a solvent for cleaning and degreasing of pipes before the run was started and in toluene based adhesives. Once present in the cabin, it is very hard to remove, especially from areas of low air movement.

Two-ethyl butanol was found in a concentration range of 0.32 to 3.5 ppm. It is formed upon hydrolysis of the thermal conditioning fluid, Coolanol 35, a triester of orthosilicic acid. Escaping Coolanol is usually absorbed by the insulating material of the fluid lines. The high temperature of some of the lines that carry heating fluid causes formation of two-ethyl butanol as well as carbon monoxide. In previous manned operation of the space cabin, when Coolanol 25 was used, there was a close correlation between these two degradation products. During the 60-day run, where the Coolanol 35 was used as the coolant, the levels of these two compounds were considerably lower.

Testing for minor contaminants in very minute concentrations were carried out by condensing large volume air samples (about 20 liters) from the SCS in a freeze-out trap. This trap consisted of three stainless steel traps immersed in progressively colder refrigerants from -20°C to -196°C. The trapped materials were analyzed by gas chromatography, mass spectrometry, and infrared procedures. In addition to the three compounds previously described, this procedure showed the presence of ethane, propane,

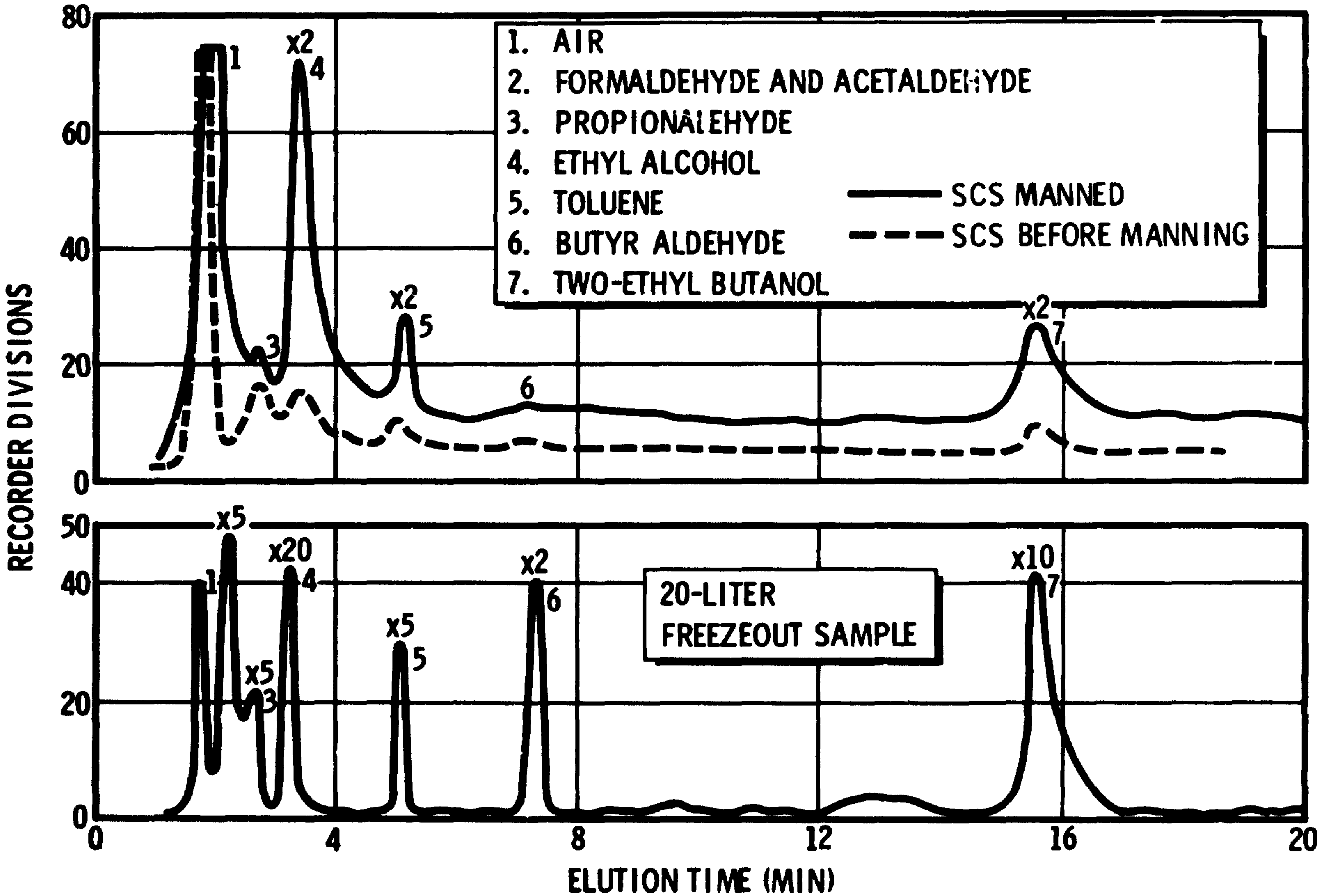


Figure 34. Chromatograms of Trace Contaminants in Atmosphere of Space Cabin Simulator

acetaldehyde, formaldehyde, propionaldehyde, and butraldehyde. In view of the large volume size, the concentrations of these contaminants were exceedingly small and certainly not toxic for short duration missions.

Many inorganic contaminants and a few organic compounds that cannot be readily determined by gas chromatography were analyzed by conventional wet-chemical procedures. Comparison of the test data between the present and previous runs showed a few important differences. These differences may be attributable to the operation of the water recovery subsystem inside the cabin. The differences were most pronounced with regard to ammonia and oxides of nitrogen. In previous runs, the average ammonia level inside the space cabin was approximately 0.5 ppm. This compares with an average ammonia concentration of 6.3 ppm found during the 60-day run. On day 50, the ammonia level steeply increased to 17.4 ppm and the crew members reported a distinct ammonia odor. Each time the used wick in the potable water recovery subsystem was replaced by a new wick, the ammonia concentration soon dropped to an unnoticeable level.

Nitrogen oxides, nonexistent in the atmosphere in previous manned space cabin operations, were found during the 60-day run. Average concentration was 0.11 ppm, peak values were 0.5 to 0.7 ppm. The oxides of nitrogen may have been formed by the catalytic oxidation of ammonia when it passed through the catalytic burner. Oxides of nitrogen are undesirable inside the cabin even in very low concentrations because of their ability to convert innocuous organic structures catalytically to more harmful oxidation products.

Increases of a minor nature were also observed in the sulphur dioxide and formaldehyde levels during the 60-day run as compared with previous tests; they do not appear to be of particular importance, unless their concentrations increase further.

4.4.1.3 Aerosol Particle Counters

During the 60-day test, measurements of aerosol concentrations within the SCS were taken. The purpose of this experiment was to:

1. Determine the variation of airborne particle size distribution and concentration with time within a closed space cabin environment.

2. Determine the gross chemical and physical constituents of this aerosol.

3. Operationally check instrumentation in a simulated flight situation.

The test equipment used for this experiment consisted of an Aerosol Particle Analyzer (APA) and a membrane filter (MF) for the collection of an integrated air sample. Both instruments were supplied by the NASA Electronics Research Center (NASA/ERC) for the duration of the test period.

The APA is a multi-channel, battery-powered sampler used to determine the purity of the SCS atmosphere with regard to particulate matter. The particle counter was capable of sorting aerosol particles in the range from 0.5 to

10 microns into five size groups (channels 1 through 5). The instrument weights less than 5-1/2 lb and has envelope dimensions of 3.75 x 5 x 7.2 in. The instrument sampled 1/60 cu ft of air during a 1-minute operating period and sorted the information obtained on the light scattered from each particle into the appropriate size group. At the end of the measurement period, the instrument was programmed to sequentially display the five size group concentrations and then turned off.

The external configuration has no protruding or sharp edges that could cause abrasion or damage to objects within the SCS. The particle intake is located in the upper right hand section, and the exhaust is to the left of the intake. The left-hand window on the face of the instrument is for a Nixie display of digits from 0 to 5 to indicate instrument operation and channel numbers. respectively. The long right-hand window is a four-digit decimal display of the number of particles counted in each channel.

Operation of the unit is achieved by pressing the INITIATE CYCLE button. The particle count will then be displayed on Nixie tubes after the sample is taken and analyzed. This control button and the two display windows are the only aspects of the instrument with which the operator must be concerned. The APA was mounted on a chain and worn over the shoulder for safety purposes. Samples were collected from the command and kitchen areas and near the delivery and return of the air distribution subsystem.

The MF is a battery-powered, diaphragm pump with a known flow rate which is suitable for air sampling with a membrane millipore filter. The handheld sampler is housed within a grey plastic case, is approximately 5-1/2 x 4 x 2 in. in size, and weights less than 2 lb. The filter was attached to the inlet of the pump air stream by means of a 3-in. rubber hose. The single control on the sampler was an ON-OFF switch.

The MF was used to collect aerosols from a large air volume onto millipore filters during a 3-hour sampling period. The particles of various sizes that collected on the surface of the millipore filter element were counted to determine the existing particle number concentration and dust loadings in the cabin during the sampling period. The battery of the pump was recharged outside of the SCS for 16 hours after each 3-hour sampling period. The filter was changed after each sampling period. Filters were returned to NASA ERC for analysis.

Daily aerosol samples were collected by the crew members specifically assigned to this task. Completed data sheets and used filters were returned to the Harvard School of Public Health for analysis and counting. This report presents information from the Harvard School of Public Health on aerosol concentration, size distribution, and the chemical nature of the ambient aerosol.

Total particle count data for the entire test, as determined by the membrane filter technique, are summarized in Table 23. These data indicate that the average concentration of particles greater than 1 micron was 18.9 thousand particles per cu ft, and for particles greater than about 0.6 microns, the average value was 46.8 thousand particles per cu ft. These low values reflect the cleanliness of the air within the cabin environment and correspond to Federal Standard No. 209, Class 100,000, White Room Installation. The

Table 23

SUMMARIZED MEMBRANE FILTER TEST DATA

	Concentration (Thousands of Particles per cu ft)	
	>1.0 micron	>0.6 micron
Range	6.5 to 61.4	14.4 to 112.7
Average	18.9	46.8

measured particle concentrations also indicate a very gradual decline in the number of particles existing in a closed space cabin over a long period of time.

When the data from the APA unit were reviewed, much the same decrease in aerosol numbers is observed, even though these data were collected eight times more frequently than the membrane filter data. Figure 35 shows the averaged daily total APA counts for four sampling locations with the exception of the period between test day 34 to 50 when the APA unit was returned to NASA/ERC for repairs. The gradual decline in the aerosol concentration within the cabin is apparent. As noted in this figure, certain specific operations were responsible for some of the peaks seen at various times, but in general, the average was declining.

The thermal control subsystem in the SCS was fitted with a fiberglass air filter which collected a significant amount of dust during the test. By assuming that this deposit was representative of the airborne dust in the SCS, it was possible to use it to determine the chemical composition of the airborne dust.

Of the deposited dust, approximately 15 percent was found to be siliceous. Silica could originate from any of the fiberglass materials present such as bedding covers, equipment covering, or the Beta-cloth garments worn by the test crew. In addition to the siliceous materials, approximately 15 to 25 percent of the deposit on the filter was found to be skin scales. The skin scales were identified by analyzing the sample of the filter cake for urocanic acid. Urocanic acid is unique to mammalian skin, and its concentration in skin is well known. A brief summary of the composition of the dust collected on the fiberglass filter is shown in Table 24.

A comparison of the number of aerosols counted inside the SCS with the aerosols found in the working area adjacent to the simulator is shown in Table 25. Major differences in particle counts are apparent for channels 2 through 5. They are only in part due to the pressure differences at the two sampling locations, but more importantly, they further confirm previous findings of a fairly high air purity existing within the SCS.

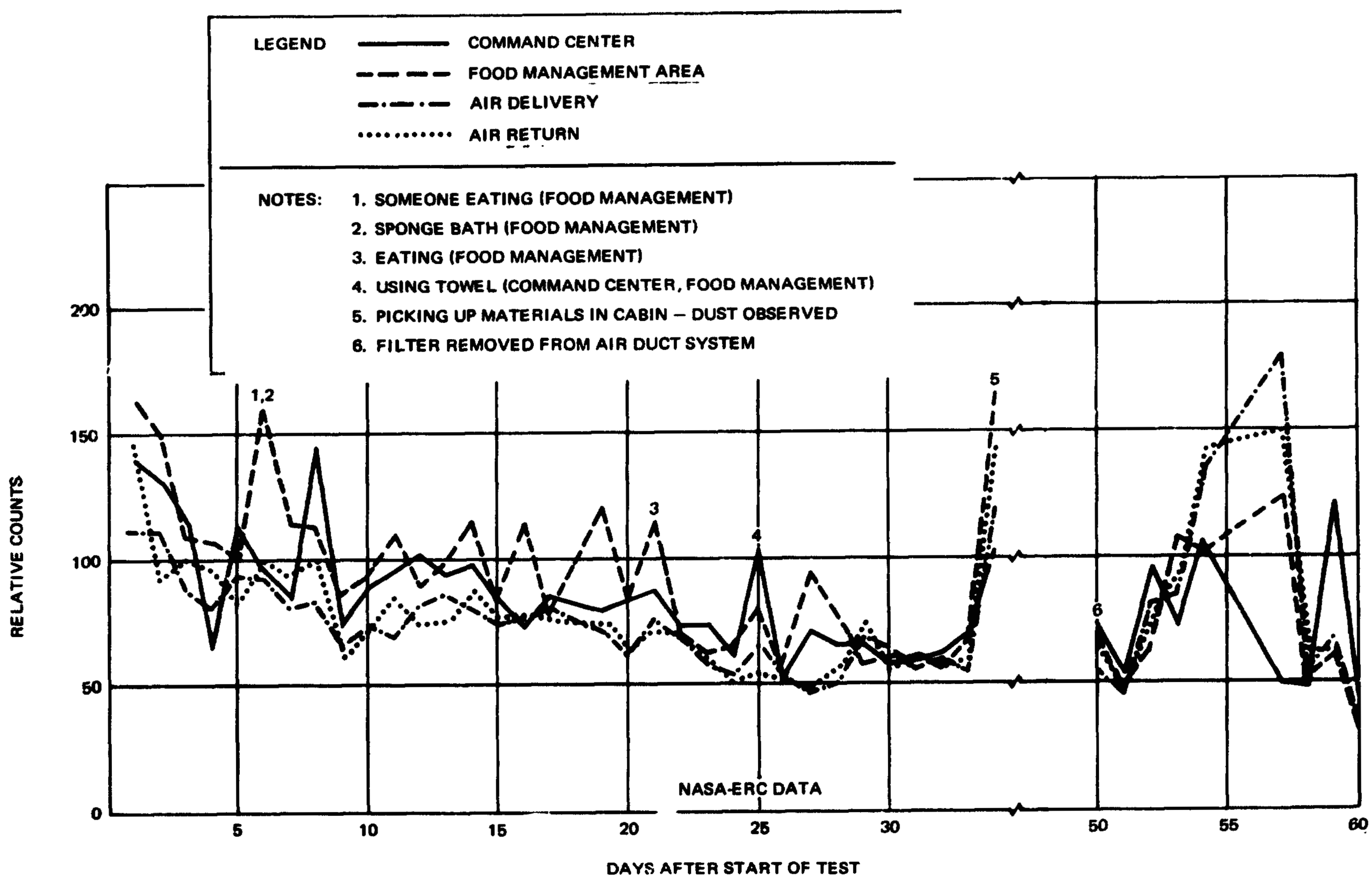


Figure 35. Relative Aerosol Concentration, Daily Averaged APA Data – All Channels

Table 24

COMPOSITION OF DUST COLLECTED ON FILTER REMOVED FROM THERMAL CONTROL SUBSYSTEM

Material	Percent
Moisture (loss at 110°F)	9
Ash (muffle at 550°C)	32
Siliceous 15	
Balance 17	
Skin Scales	15 to 25
Volatiles	34 to 44

Table 25

COMPARISON OF AEROSOL PARTICLE COUNTS INSIDE AND OUTSIDE SCS

	Number of Particles	
Channel*	Working Area Close to SCS	Inside SCS Galley
1	0000	0000
2	0143	0004
3	0335	0064
4	1105	0255
5	4526	0589

*Indicates range of particles measured (0.5 to 10 μ) with larger particles measured by Channel 1.

4.4.2 Carbon Dioxide Concentrator

The carbon dioxide concentrator removed carbon dioxide from the atmosphere by selective adsorption in cyclically regenerable beds, and transferred this carbon dioxide, under pressure, to an accumulator for processing by the Sabatier reactor.

4.4.2.1 Description of Equipment

Prior to the start of the test, the carbon dioxide removal and concentrator unit was redesigned and upgraded from the configuration used in previous tests (Reference 3). The new design provided the following features:

1. Improved vacuum-tight transfer valves.
2. Improved vacuum pumps for desorbing carbon dioxide into the accumulators
3. Modular construction for ease of repair.
4. Dry nitrogen purge if required for silica gel desorption.
5. Improved condenser for water vapor leaving the desorbing silica gel bed.
6. More complete and sophisticated instrumentation.
7. Additional cycle timing capability.

In addition, the capability to vary operating parameters was retained, including adsorption/desorption cycle times, heating temperature, heating/cooling rates, adsorption/desorption gas flow rates and vacuum requirements. Figure 36 shows the improved unit.

The normal mode of operation was as follows: atmospheric gas was taken from the potable water recovery subsystem, or humidity control subsystem, downstream of the condenser-separator, entered a four-way selector valve, and passed through a silica gel bed (No. 2), where the water vapor was removed, thereby reducing the dewpoint to approximately -50°F. The gas then passed through another four-way selector valve and entered the heat exchanger which removed the heat generated by adsorption in the silica gel bed; then through a three-way selector valve into the molecular sieve bed No. 2 to remove carbon dioxide; through another three-way selector valve, and back into the cabin. Silica gel bed No. 1, previously loaded with moisture, was desorbed by a portion of the exit flow diverted downstream of the molecular sieve bed while heating the silica gel bed to about 300°F. Water vapor in the gas stream leaving the desorbing silica gel bed was removed by a condensing heat exchanger, to prevent condensation in the exhaust line and blockage of flow. This water was normally pumped to the potable water recovery subsystem for processing. As explained in Subsection 4.3, Water Management this was done for the first 10 days of the test. After day 10, the water was diverted to the waste tank for discard since this water was not required.

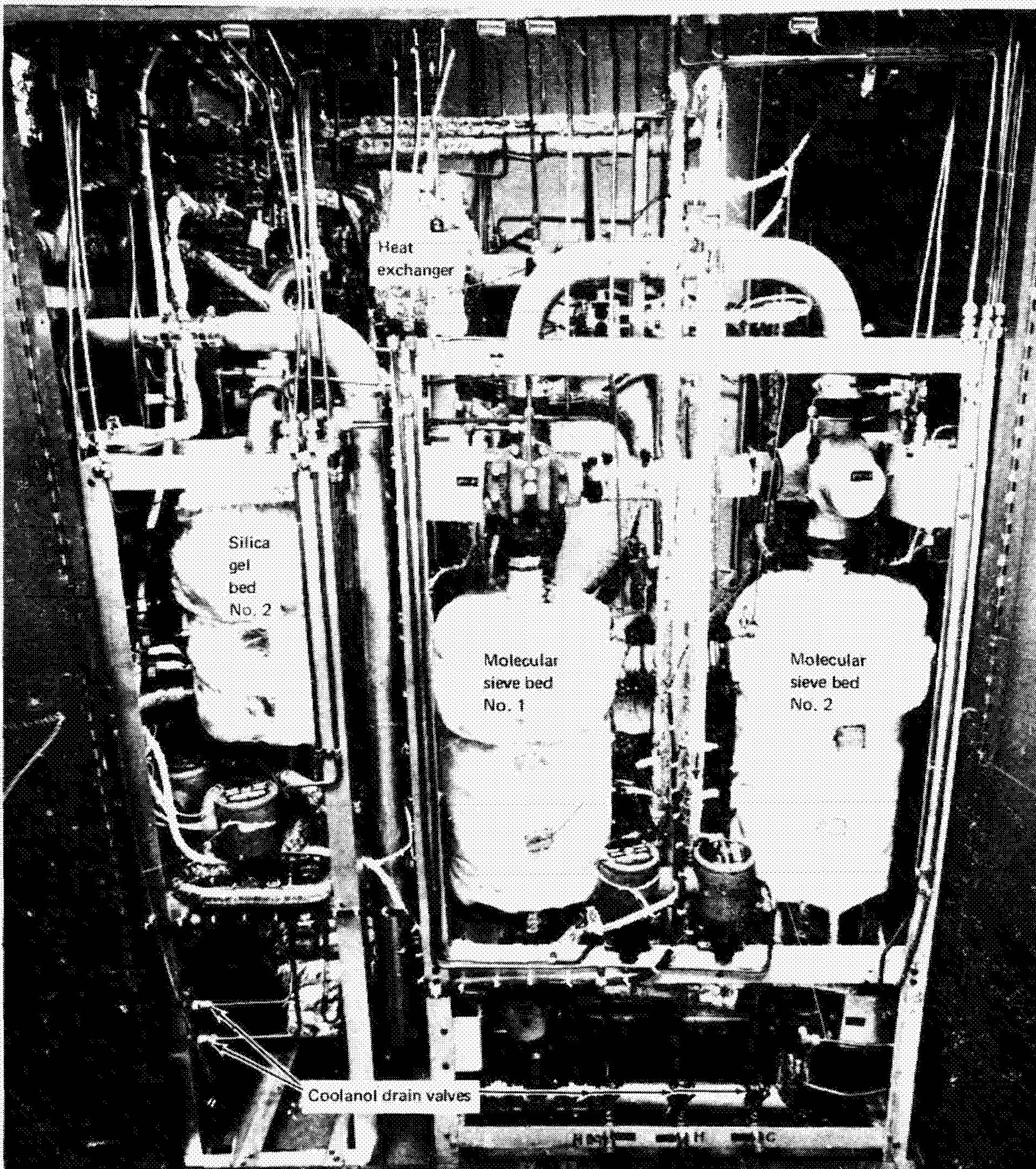


Figure 36. Front View of the Carbon Dioxide Concentrator Unit

Simultaneously, molecular sieve bed No. 1. previously loaded with carbon dioxide, was regenerated. The sequence of operations for the regeneration of the molecular sieve bed was as follows: the atmospheric gas in the canister was first removed by the use of one or both of the internal vacuum pumps, pumping out the gas in the bed canister for about 3 minutes to the cabin atmosphere, while hot thermal conditioning fluid was flowing through the coils in the molecular sieve bed to heat it up and drive off the carbon dioxide. After the 3-minute purge period, the pump discharge valve was switched to pump the evolved carbon dioxide into an accumulator of about 7.4 cu ft volume for delivery to the Sabatier reactor.

After desorption of about 30 minutes, the molecular sieve bed was cooled by circulating cold fluid in the heat transfer coils of the canister. By the time one adsorbing bed was loaded, the other was fully rejuvenated and ready to put on stream.

At the end of the adsorption portion ot the timing cycle, seven valves were switched automatically so that the rejuvenated silica gel and molecular sieve beds were used for adsorption. Approximately 20 percent of the gas stream flowed through silica gel bed No. 2 to purge water vapor from it. Molecular sieve bed No. 2 was purged of residual cabin atmosphere, desorbed of carbon dioxide, cooled, etc., as was done in molecular sieve bed No. 1. Total cycle time was 90 minutes. Figures 37 and 38 show the carbon dioxide concentrator unit switches, valves, indicator lights, power meters, pressure gages, and flow indicators for Coolanol 35 and the cabin atmosphere. A schematic of the unit is shown in Figure 39.

4.4.2.2 Operating Mode Description

The normal mode of operation was to desorb the carbon dioxide from the molecular sieve beds into an accumulator for use by the Sabatier reactor for recovery of oxygen, as described above. An alternate mode or desorption consisted of venting the carbon dioxide through a diverter valve (Figure 39), to simulated space vacuum (less than 1 mm Hg). In the overboard desorption mode, at the start of the desorption cycle, the internal vacuum pump was turned on for 3 minutes while the diverter valve was switched from space vacuum to the INTERNAL position with the pump discharge solenoid valve positioned to pump the residual gas from the canister to the cabin. After the 3-minute purge period, the diverter valve was switched back to the space vacuum position and the internal vacuum pump turner off. This mode of operation was used during the 60-day test when the Sabatier reactor was inoperative due to a failure of the temperature controller.

A bakeout mode was provided to rejuvenate the molecular sieve beds which could be poisoned by water after long periods of operation or due to a subsystem malfunction. In this mode the cam timer was shut off and both beds manually placed on a heating cycle for about 1.5 hours while exposing the beds to the simulated space vacuum.

4.4.2.3 Subsystem Performance

Figure 40 presents performance characterisitcs of the regenerative molecular sieve carbon dioxide removal unit during the 60-day test. The average cabin carbon dioxide level was below 1.1% by volume, or 3.9 mm Hg, during the 60-day test.

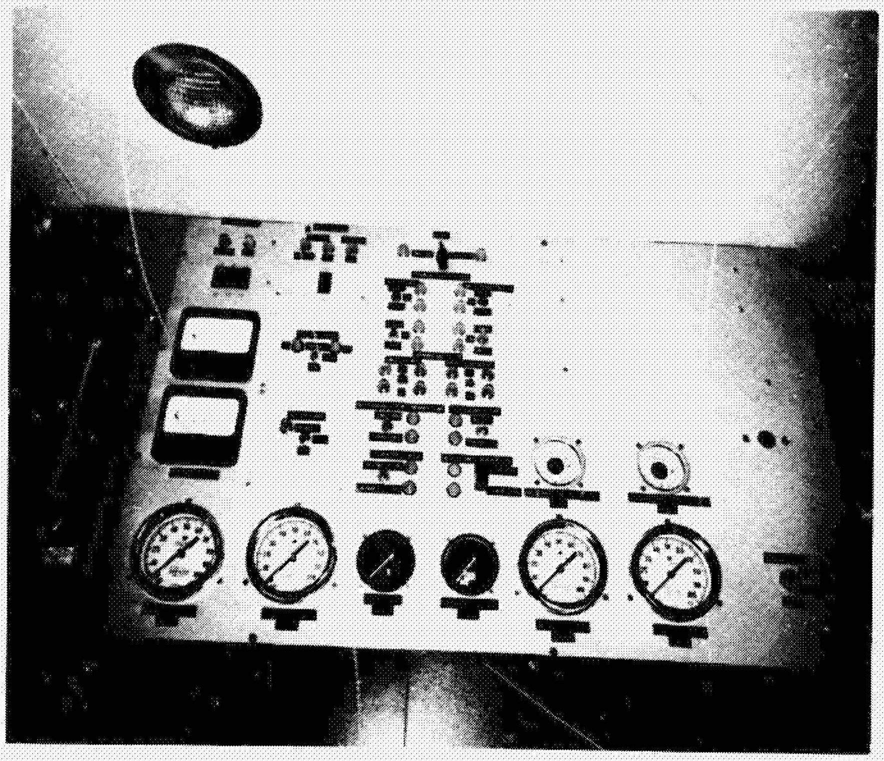


Figure 37. Carbon Dioxide Concentrator Switch Panel

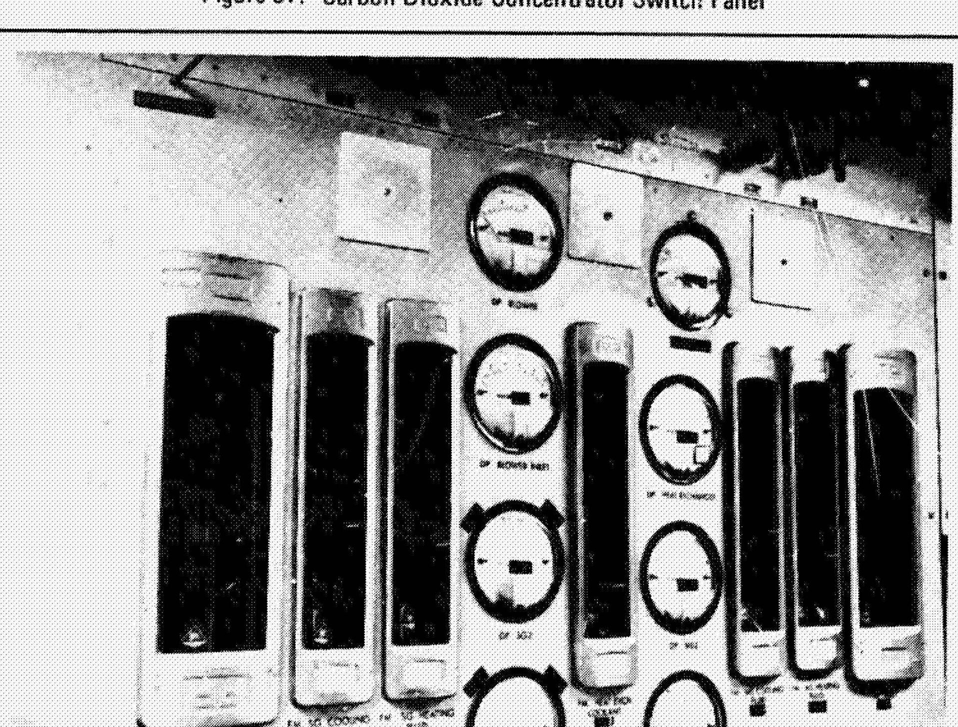


Figure 38. Carbon Dioxide Concentrator Pressure Gages and Coolanol 35 Flow Indicators

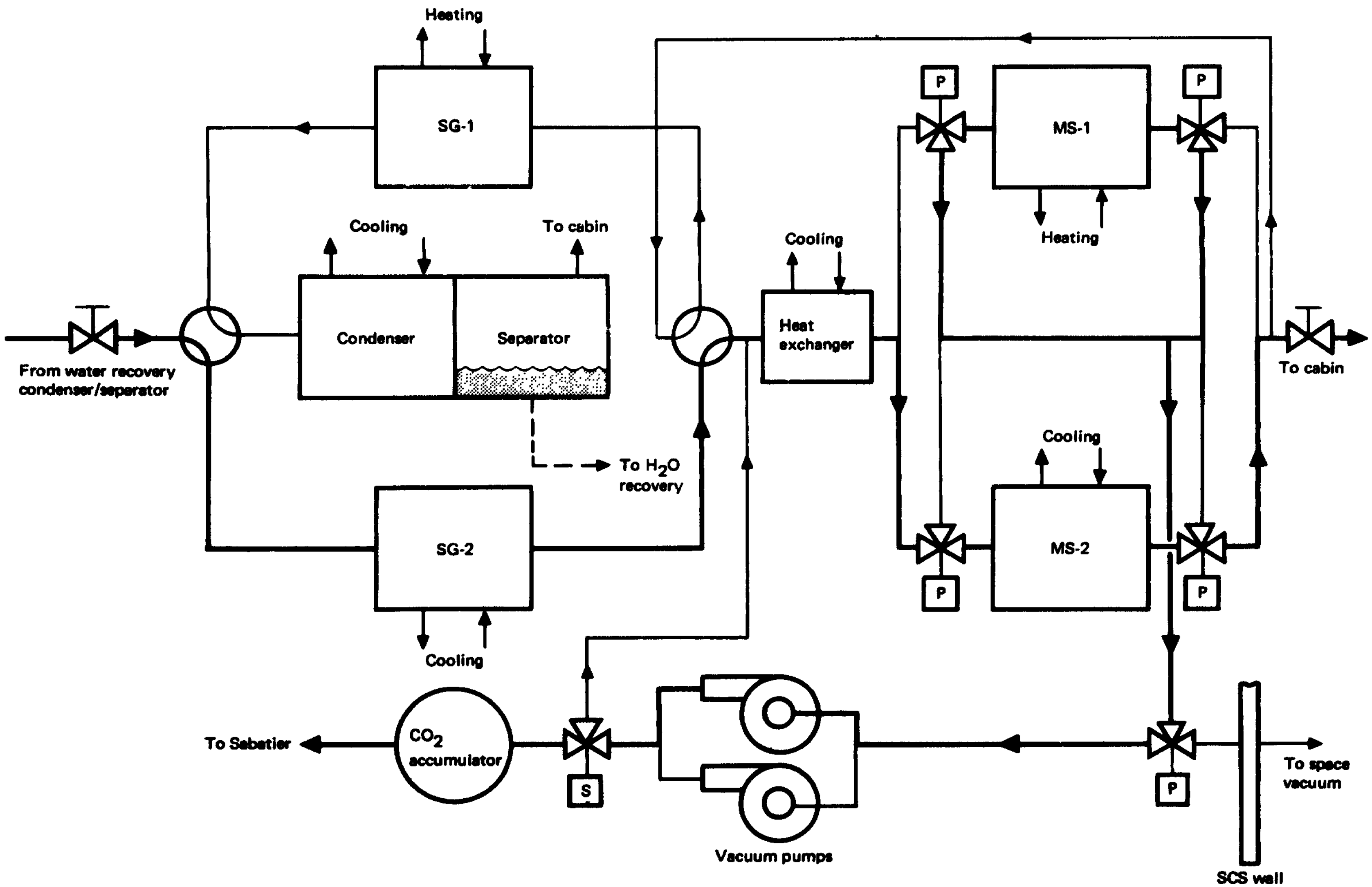


Figure 39. CO_2 Concentrator Unit

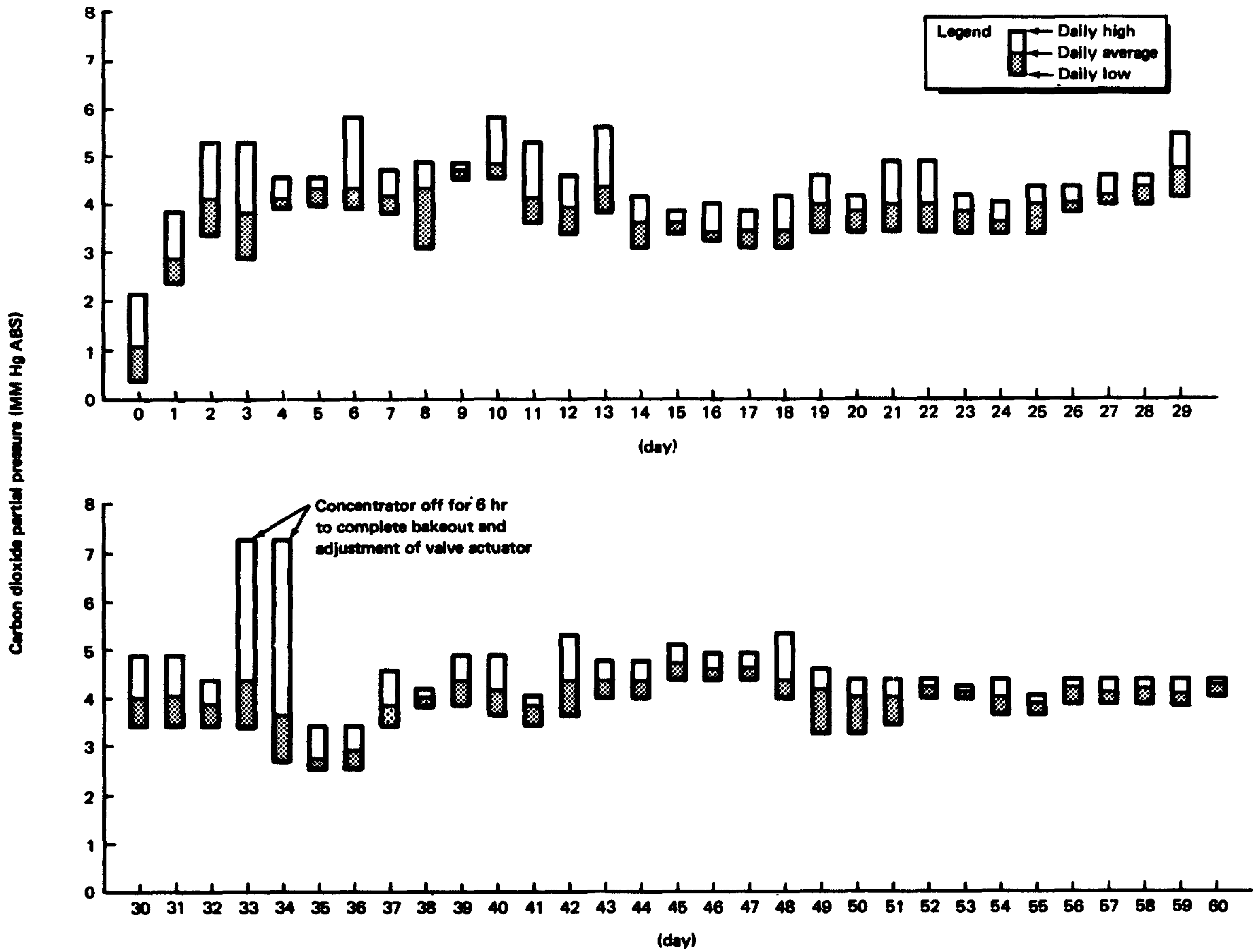


Figure 40. CO_2 Concentration in Cabin during 60-Day Test

Figure 41 shows representative breakthrough curves obtained 5 days before and 3 days after a bakeout operation was performed. The degradation of bed performance shown normally occurs because of the inability of the internal vacuum pump to fully desorb water from the sieve material. The condition can be corrected by the bakeout operation which was described in the previous section.

A typical temperature and pressure history during normal bed desorption is presented in Figure 42. This compares with calculated data and will be used to update computer programs. The concentrator maintained the design value of carbon dioxide concentration in the cabin and transferred desorbed gas of excellent purity to the accumulator for delivery to the Sabatier.

The reliability of the unit was very high. During the test it required the replacement of a time delay relay, adjustment of a flow diverter valve, and cleaning the vacuum pumps once to remove molecular sieve dust. The molecular sieve dust, deposited in the vacuum pump inlet manifold, is shown in Figure 43. In addition, one cam switch of the timer did not close properly to indicate proper sequencing of one operation. Since this indication was not affecting operation of the unit, the malfunction was not repaired.

4.4.3 Trace Contaminant Control

The primary means to control trace contaminants within the SCS was the toxin control subsystem. In addition to the toxin control subsystem, some trace contaminant and odor control was provided by the large charcoal filter in the potable water recovery subsystem and by the silica gel and molecular sieve beds in the carbon dioxide concentrator.

The toxin control subsystem consisted of a particulate filter, charcoal sorbent bed/particulate filter, regenerative heat exchanger, heating element, temperature controller, catalytic burner, and blower. A schematic diagram of the subsystem is shown in Figure 44, and the installation is shown in Figure 45.

The subsystem blower drew approximately 100 cfm of cabin air into the unit through a particulate filter and out through the sorbent bed/particulate filter. A small fraction of the air from the blower discharge (approximate 0.7 cfm) passed through the flow control valve and entered the regenerative heat exchanger (economizer), where it was preheated by the exit gas stream. The bypass airflow then passed through the heater (where the temperature was elevated to the desired oxidation temperature of 700°F), through the catalytic bed, the economizer, and then to the suction side of the blower.

The operation of the subsystem was very successful during the test period, and unscheduled maintenance was not required. To evaluate carbon monoxide control capability, the subsystem was shut down twice during the 60-day test. With the toxin control subsystem shutdown, the carbon monoxide concentration in the cabin increased from 13 ppm on day 30 to 31 ppm on day 38, and from 19 ppm on day 44 to 35 ppm on day 50. In both instances, the carbon monoxide levels rapidly returned to normal after the subsystem was reactivated.

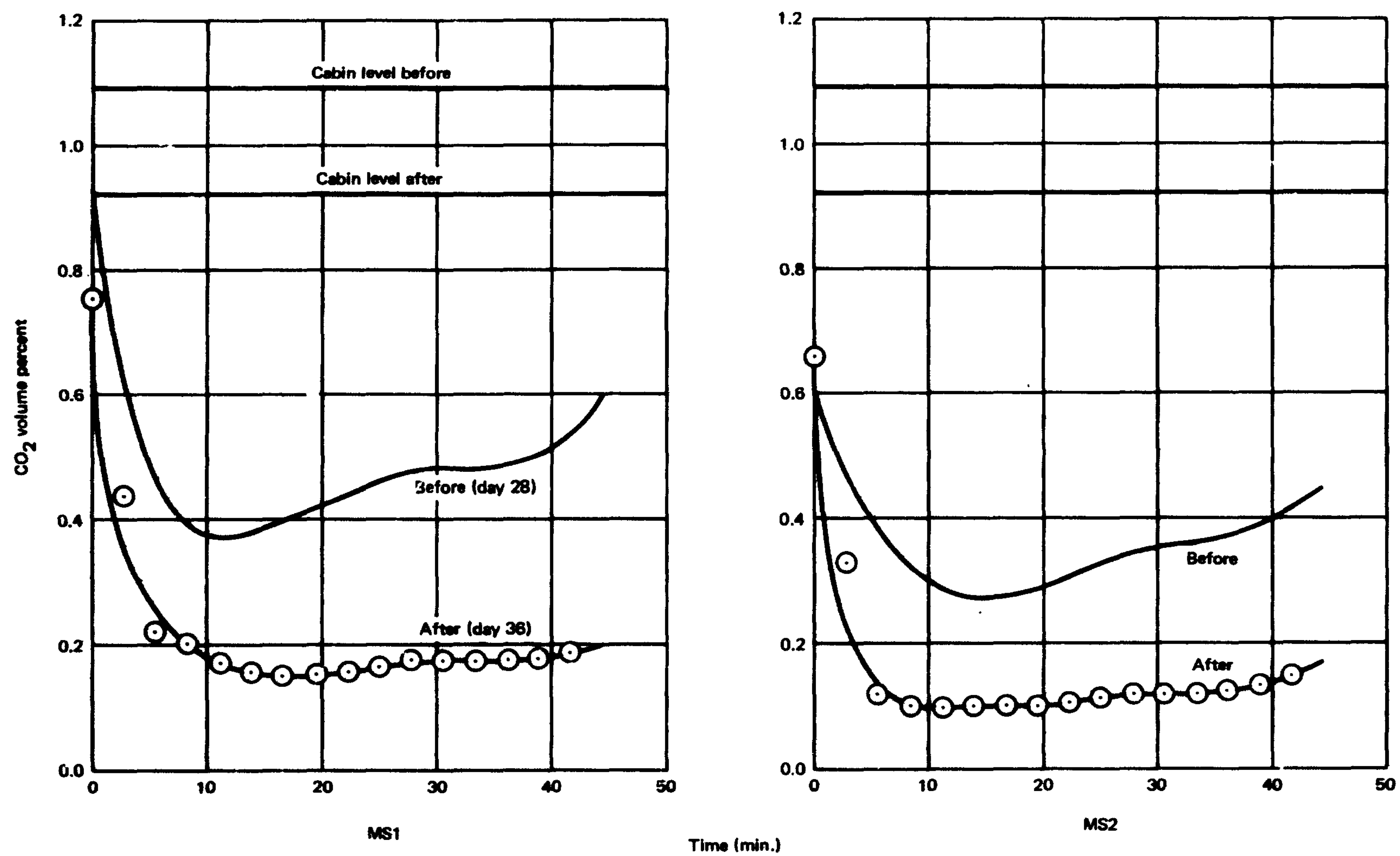


Figure 41. Typical Breakthrough Curves before and after a Bakeout of Molecular Sieve Beds – Day 33

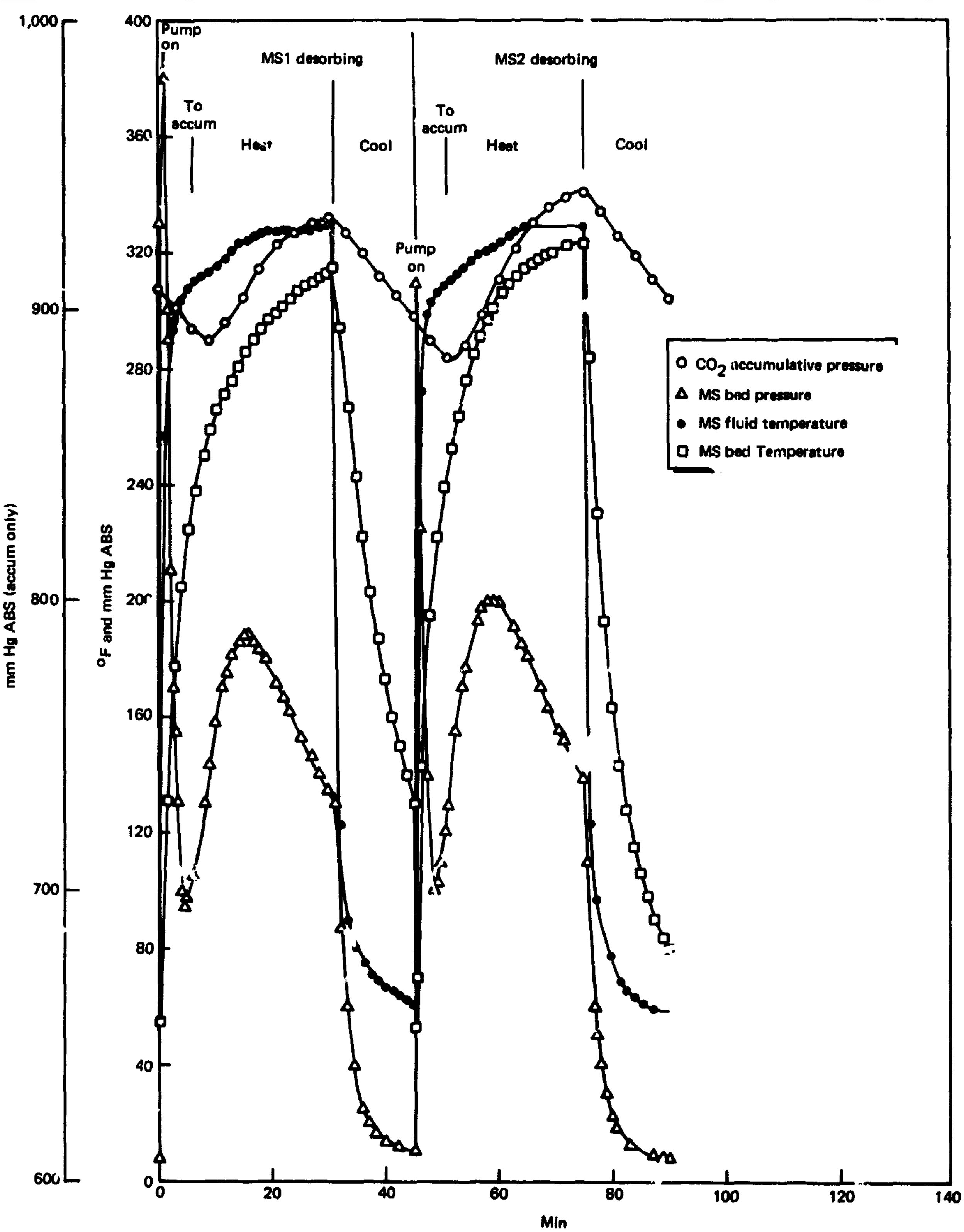


Figure 42. Typical Desorbing Molecular Sieve History--Day 52

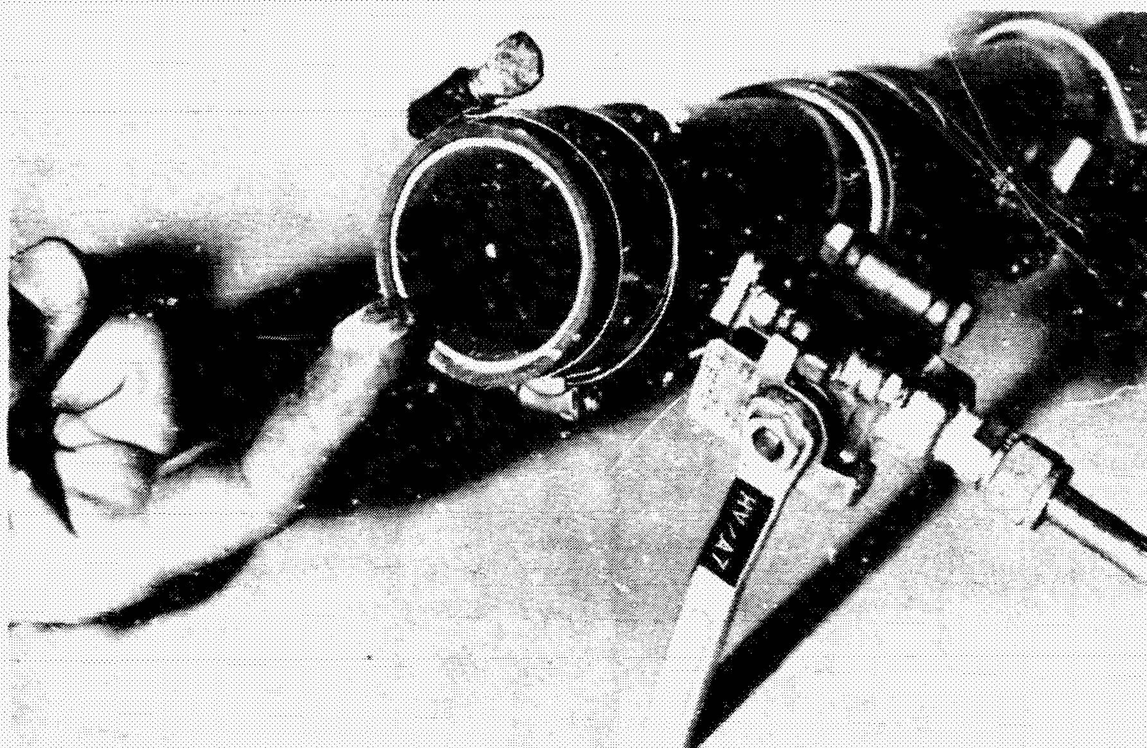


Figure 43. Molecular Sieve Du[illegible] Vacuum Pump Manifold

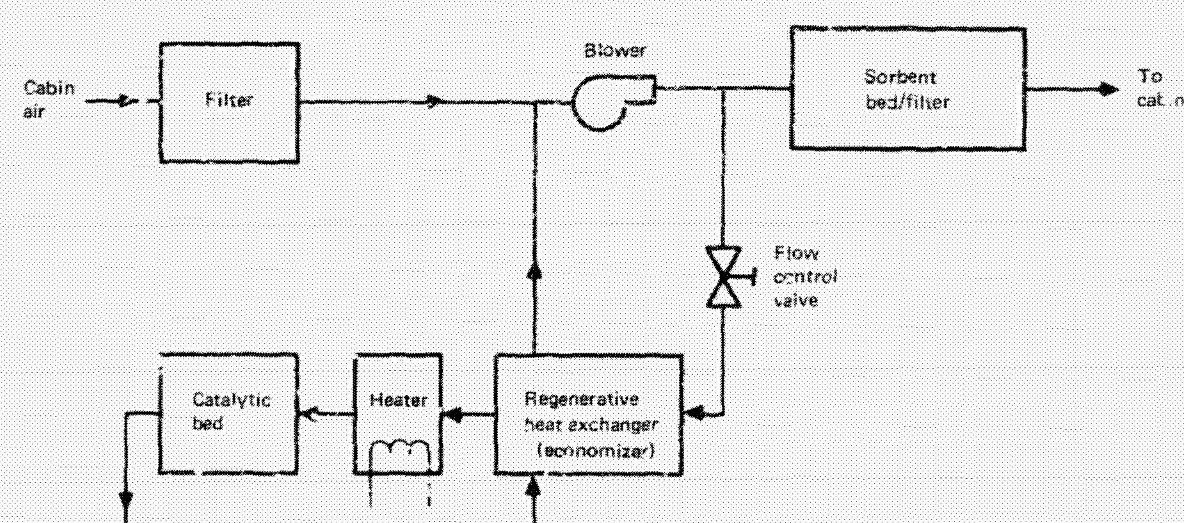


Figure 44. Toxin Control Subsystem

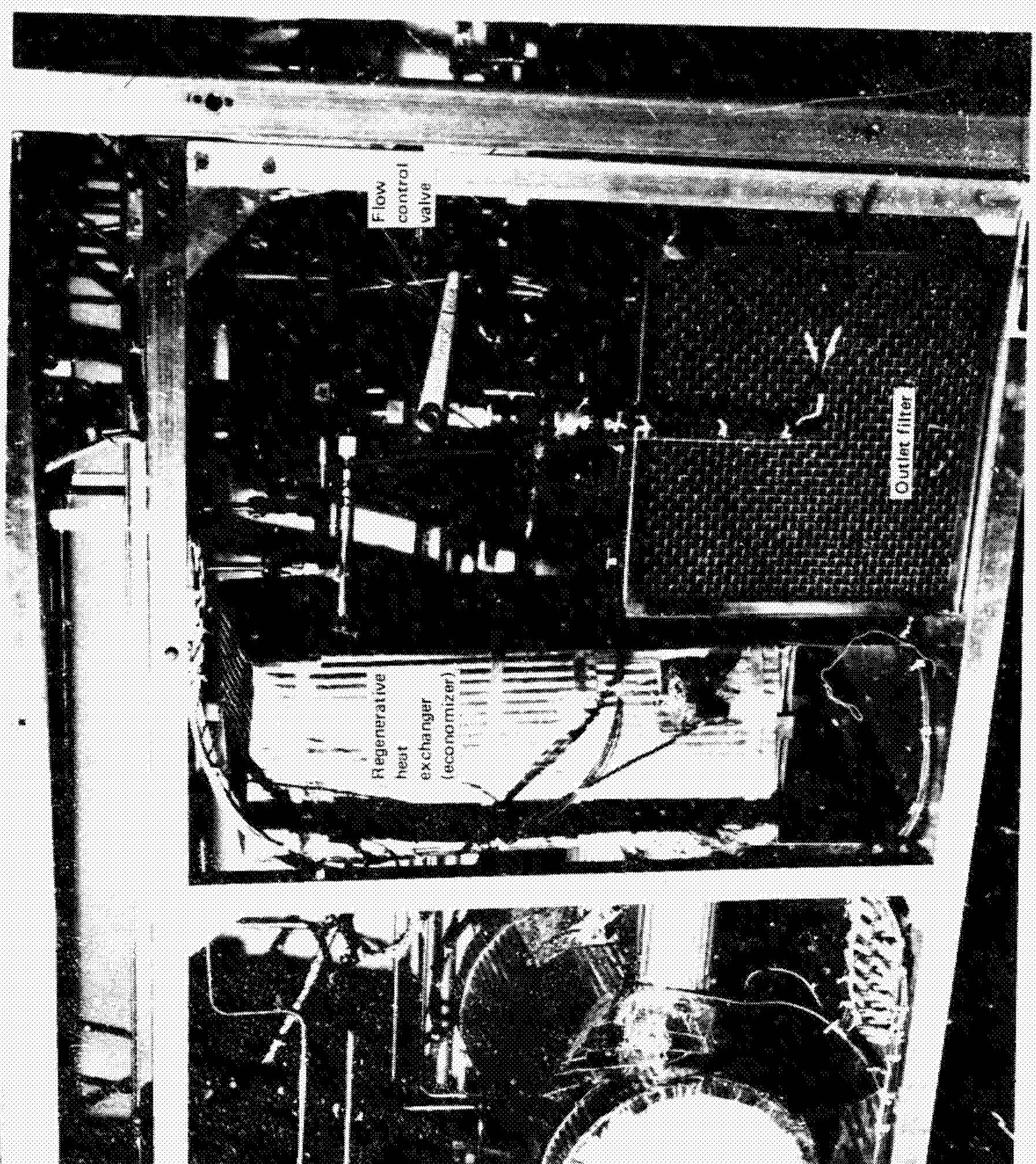


Figure 45. Side View of the Tcxin Control Unit

4.5 THERMAL AND HUMIDITY CONTROL

4.5.1 Description of Equipment

The thermal control subsystem was used to reject the sensible heat load generated within the cabin and consisted of a blower, a heat exchanger, a distribution system, and a thermostat. A schematic diagram of this subsystem is shown in Figure 46, and Figure 47 shows the control panel.

The operation of the thermal control subsystem was as follows: Cabin air was pulled from the area above the ceiling through a filter by the blower, passed across the parallel flow heat exchanger, and discharged through ceiling diffusers to various portions of the cabin.

The humidity control subsystem was to be used as a backup to the open cycle air evaporation water recovery subsystem in the event it was required to close this cycle or discontinue water recovery. The subsystem consisted of a blower and a condenser. A schematic of this system is also shown in Figure 46. The subsystem was not operated during the test period, and humidity control was done in the water recovery unit, thermal control heat exchanger, and silica gel desorbate condenser.

4.5.2 Subsystem Performance

This subsystem was successfully used in previous SCS manned tests and required only minor modifications for the 60-day manned test in the SCS. Preliminary performance testing was unnecessary; however, functional checks were made during the altitude run prior to the 5-day manned test.

On the 49th day of the 60-day test, the air flow had dropped from the initial 1,300 cfm to 930 cfm. The inlet filter was examined and found to be plugged with dust. The filter was removed and the air flow rose to 1,700 cfm. Cabin temperatures dropped correspondingly. Figure 48 shows the change in air flow during the course of the test. Temperatures within the cabin varied from a high of 85°F to a low of 65°F and the relative humidity varied from a high of 36 percent to a low of 27 percent. Figure 49 shows the range of dry bulb temperatures and Figure 50 shows the range of dewpoint temperatures within the cabin during the test period.

Because of the increased heat load introduced by the new water and oxygen recovery equipment, the capacity of the thermal control subsystem was marginal, necessitating the operation of the subsystem with coolant temperatures below the cabin dewpoint. This resulted in the condensation of water vapor from the cabin atmosphere at a higher rate than anticipated.

4.6 WASTE MANAGEMENT

4.6.1 Description of Equipment

The waste management subsystem included a General Electric Slinger Waste Management commode which was furnished for the 60-day test from the USAF Aerospace Medical Research Laboratories (USAF/AMRL). This

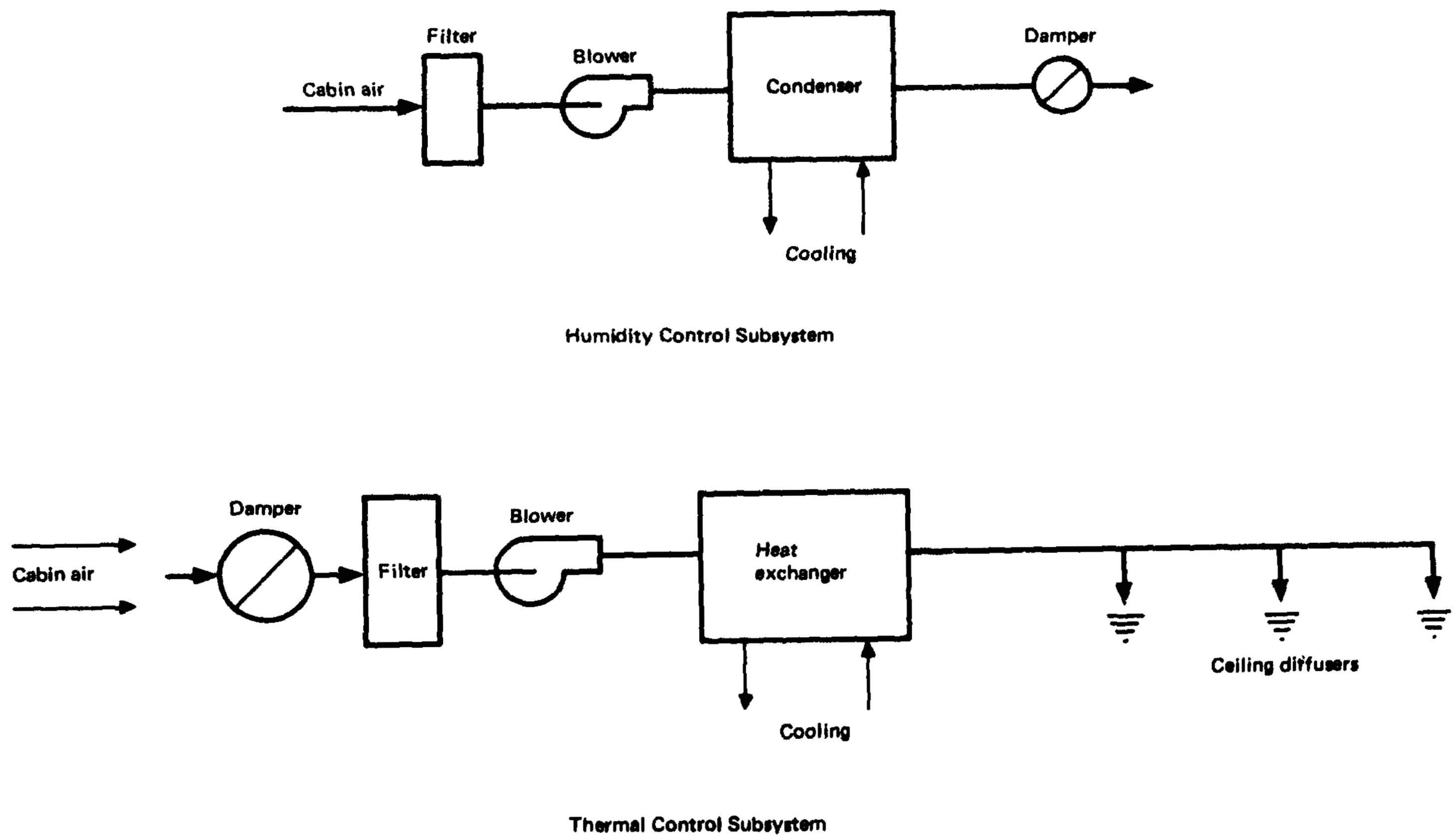


Figure 46. Thermal and Humidity Control Subsystems

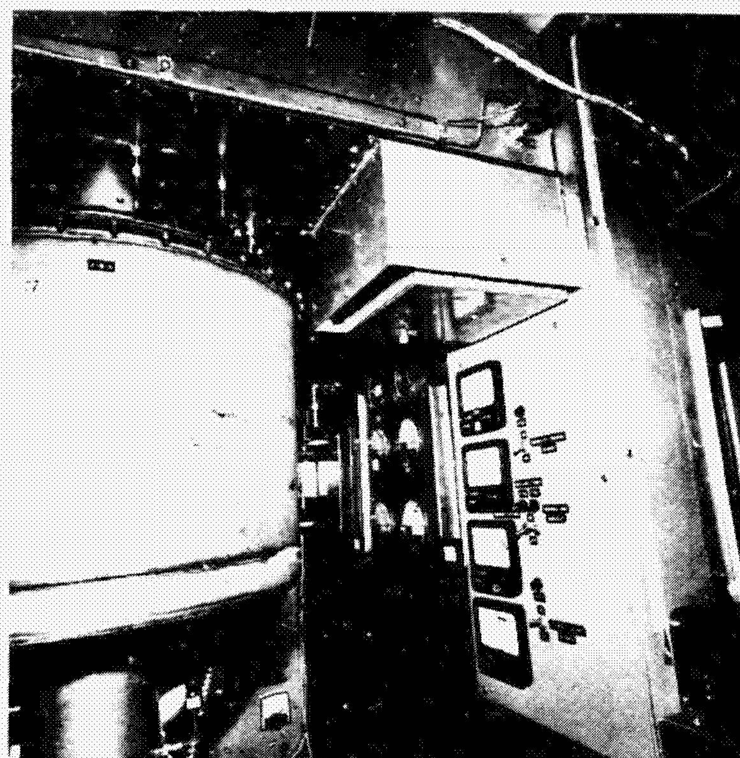


Figure 47. Thermal and Humidity Control Instrumentation Panel

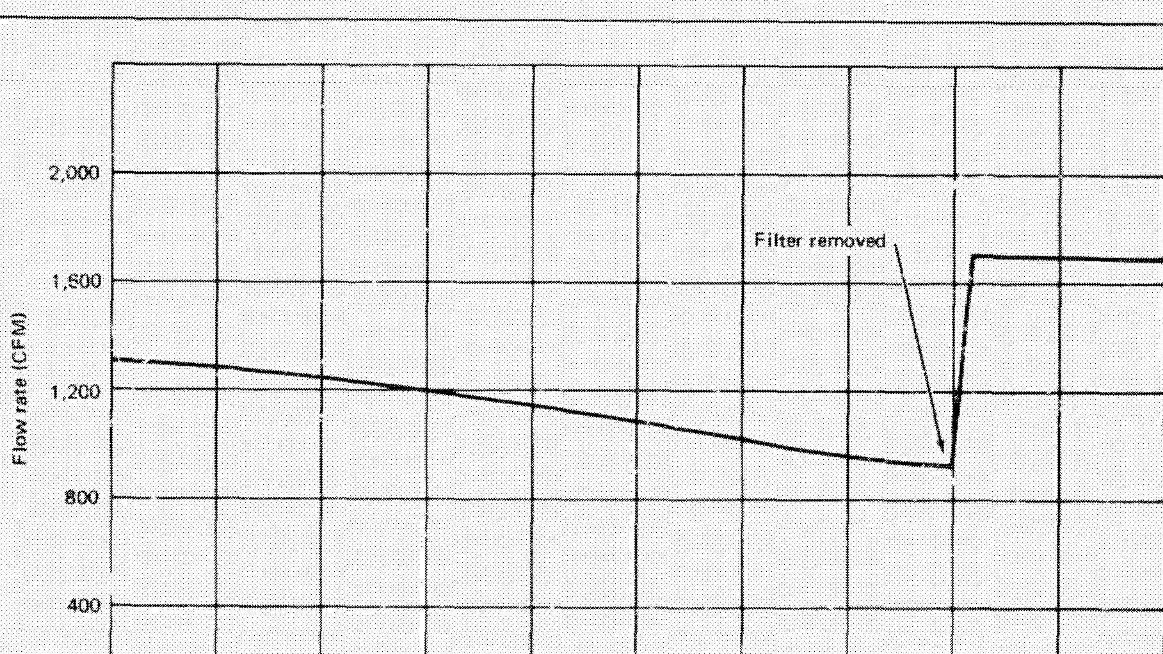


Figure 48. Thermal Control Airflow Rate

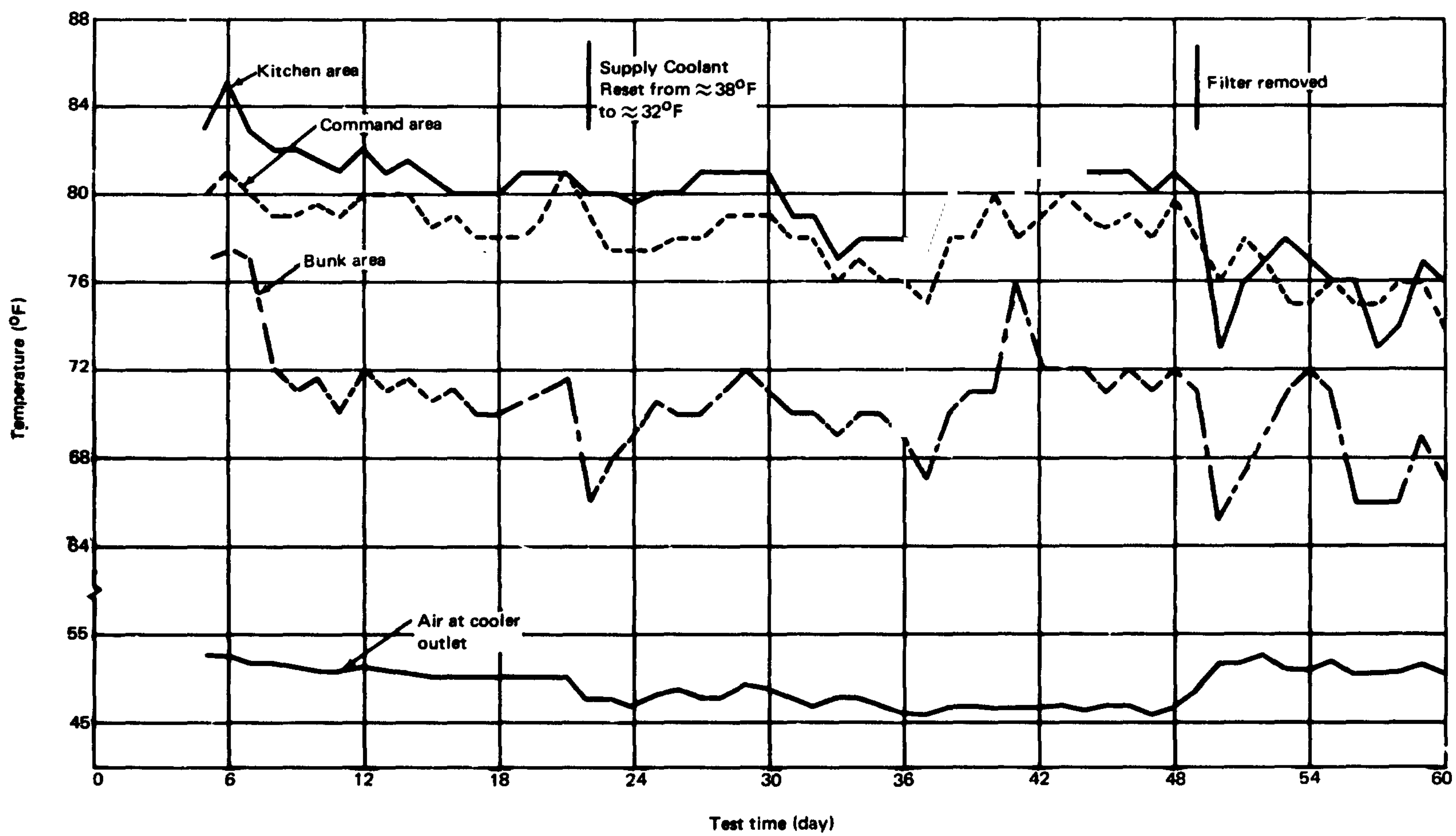


Figure 49. Daily Average of Cabin Temperature

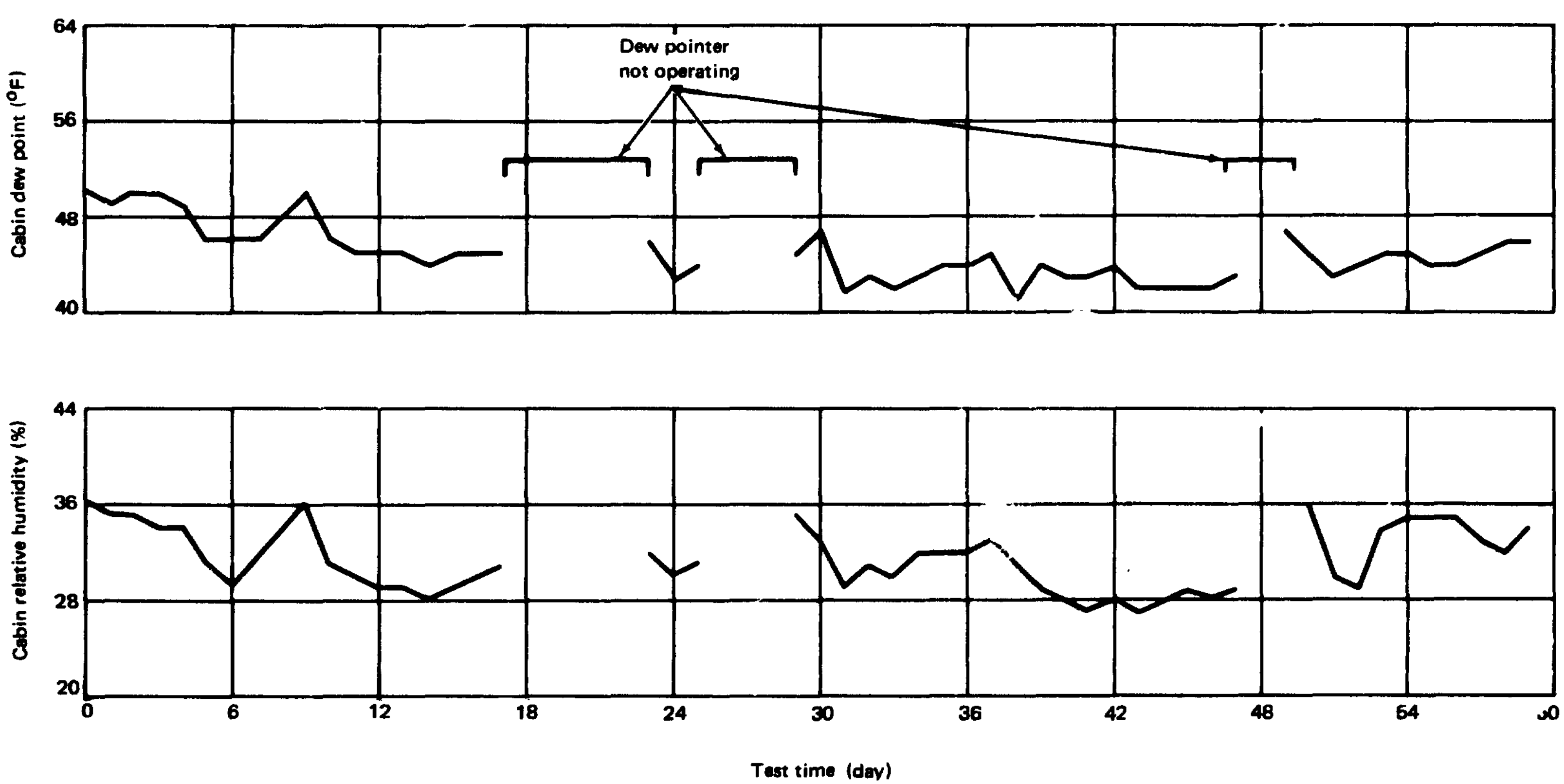


Figure 50. Daily Average of Cabin Dew Point and Relative Humidity

commode was designed to accommodate four men for 30 days, including toilet paper storage. In order to extend use beyond 30 days, McDonnell Douglas added a container for toilet paper storage. Use of this slinger unit allowed the crewmen to defecate and wipe in a normal manner. Toilet tissues were deposited in a removable throw-away plastic container housed within an airtight receptacle. The crewmen were not exposed to the waste material or odor and were not required to spend time processing fecal waste. Figure 51 shows a schematic of this subsystem. Following the 5-day checkout test at the suggestion of the test subjects, a standard toilet seat was added over the commode because the original seat contour interfered with defecation in the 1-g environment.

The feces treatment and storage unit contained internal ribs to provide structural rigidity and an extended heat exchanger surface area which facilitated vacuum drying of the feces. The opening in the slinger unit was sealed with a 4-inch diameter snap-tight closure when the unit was not in use.

The transport tube was of Tufran-coated aluminum, to provide a non-stick, corrosion-resistant surface. It has twelve 1/8-in. diameter holes for transport air flow to enter from the cabin and two holes for indexing jets. The air flowed across the buttocks and then turned approximately in the region of the anus to flow axially toward the impeller. This design provides induction of the fecal bolus during zero-gravity conditions. The indexing jets impinge upon the anus to assist positioning.

The slinger assembly consisted of the impeller with 16 tines, a drive motor and an aluminum motor mount coated with Tufran for corrosion resistance. The stainless steel impeller and tines were Teflon coated to provide a non-stick surface and had a heavy metal outer ring to provide a flywheel effect for the motor tines.

Other components of the waste management subsystem included a charcoal and bacterial filter, a centrifugal blower, two switches, and a relay. One switch closed the vacuum vent, opened the air flow port, started the slinger and started the blower. The second switch controlled the indexing jet. Three solenoid valves in the system used 115 VAC, 60 cps power and controlled the indexing jets, the transport air flow through the unit and the slinger vacuum vent. A fourth solenoid valve was used to control the vacuum to the toilet tissue storage container.

When the slinger unit was not being used, the interior was exposed to a vacuum below 2 mmHg abs. to dry the feces and prevent odors. To operate the unit, the crewmen actuated the power switch to repressurize the slinger unit interior, start the transport airflow through the unit, and start the slinger tines rotating. The snap-tight closure was removed and the seat lowered. The crewman then seated himself on the toilet seat. Figure 52 shows the commode with the modified seat, and Figure 21 before modification. The crewman defecated normally (urine was collected separately or simultaneously through the urinary funnel) and the stool was transported by the air flow into the aluminum slinger unit where it impinged on the rotating impeller. The air was drawn through the unit where via a centrifugal blower

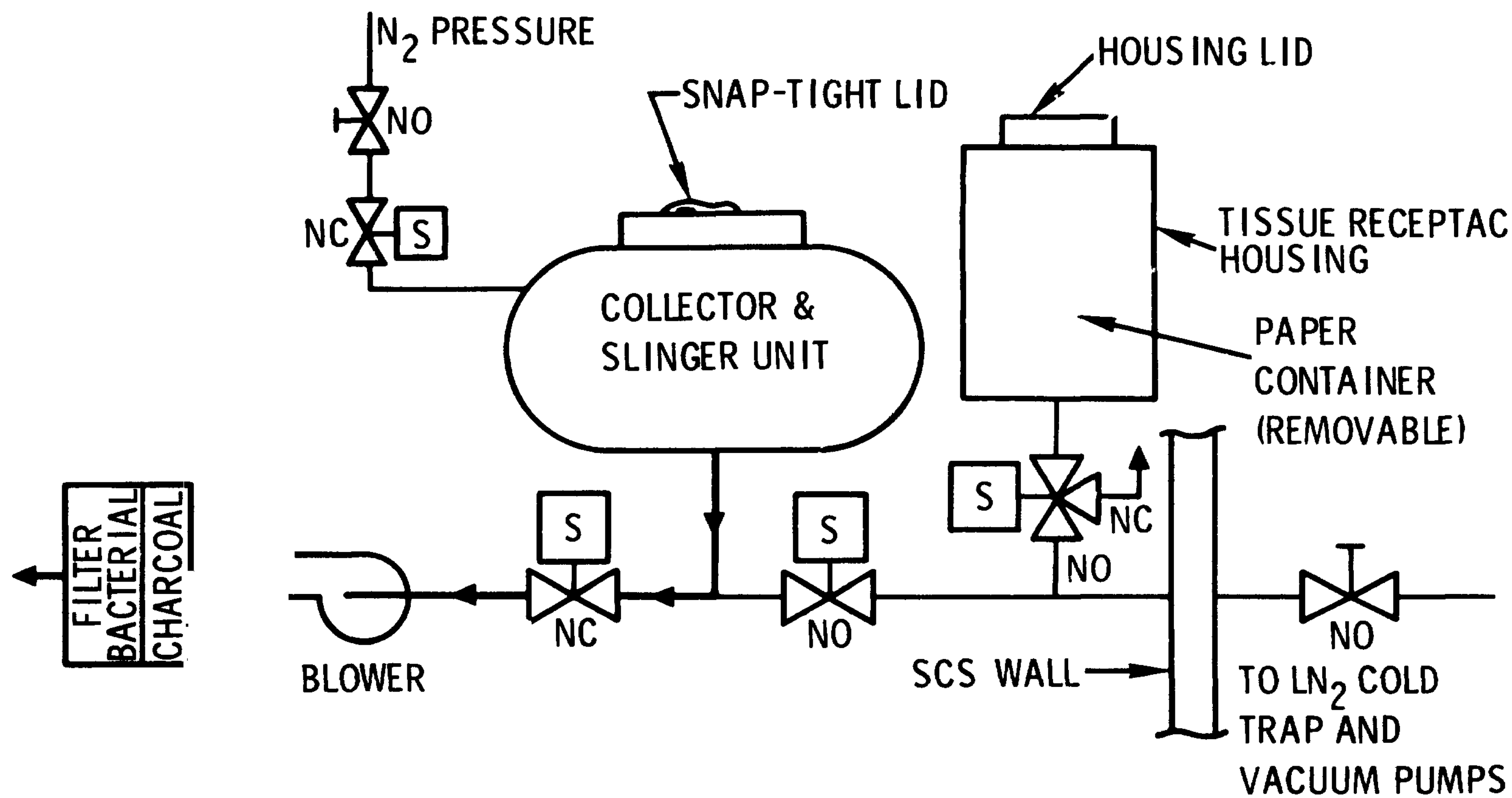


Figure 51. Fecal Waste Management Subsystem

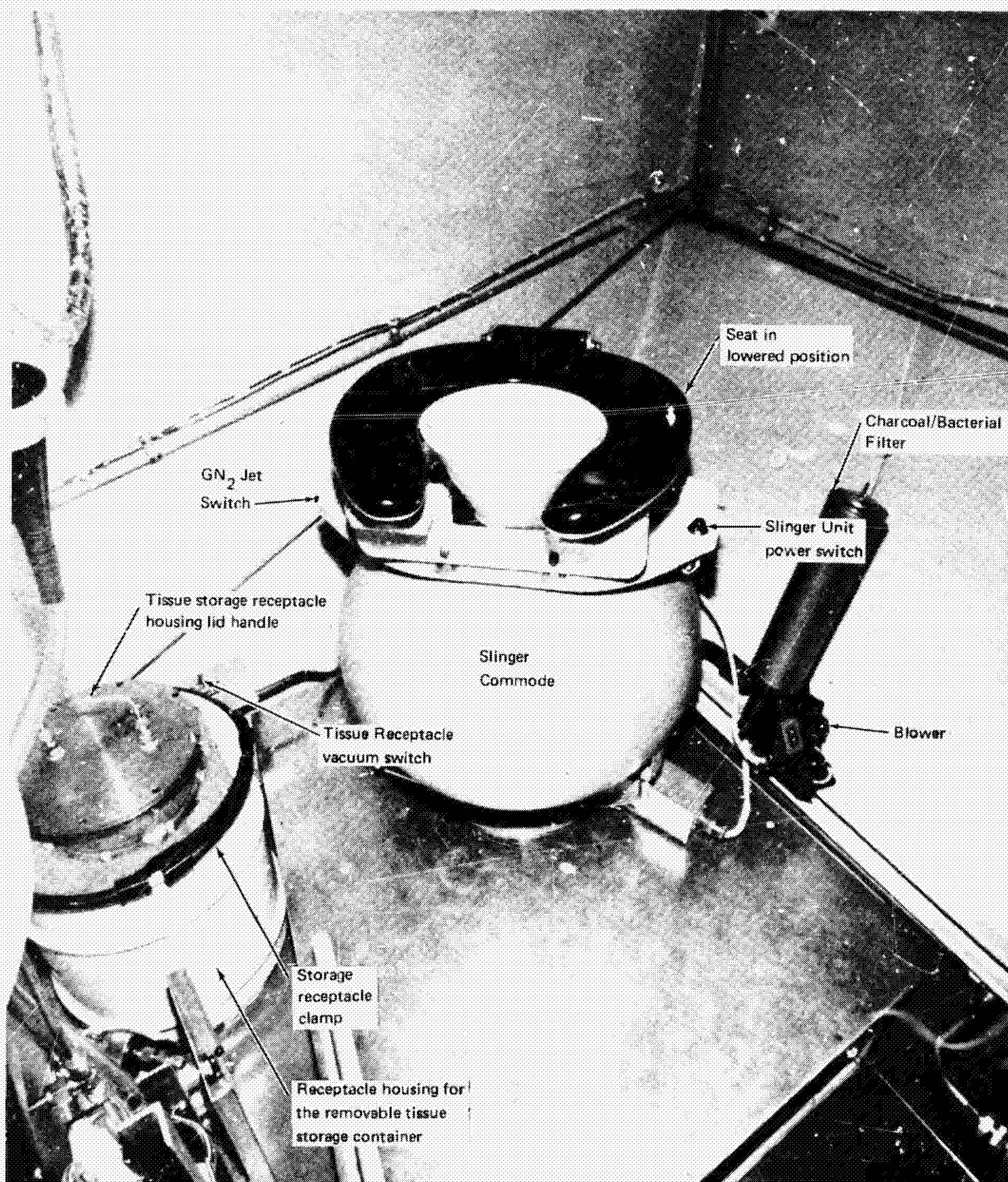


Figure 52. Fecal Waste Collection and Storage Components

at about 10 cfm and was vented to the cabin after passing through a bacterial filter and activated charcoal. The stool was centrifugally slung outward, shredded by a series of rotating tines, and spread on the slinger unit inside wall. Dense packing of the feces was achieved by this method and each layer of feces was sufficiently thin that it was rapidly vacuum dried. The Teflon coating of the impeller and tines and the outward angle of the tines prevented impeller clogging by the feces.

The toilet tissue receptacle had two covers, a small upper one for toilet paper storage access and a large clamped cover which allowed removal of the full bag of toilet paper. When the toilet tissue receptacle was not being used, the interior was exposed to a vacuum under 2 mmHg to continue drying of the feces on the tissues and to prevent odors. During use, the crewman repressurized the tissue receptacle, removed the lid, wiped his anal area, placed the used tissues in the receptacle, replaced the lid and restored the receptacle to a vacuum. After lifting the seat and replacing the snap-tight closure, the slinger-unit was sealed. The power switch was then turned off and the slinger interior was vented to vacuum.

After installation into the SCS, checkout tests included leak checks in the vacuum line. Checks on the urine collection and pretreatment components were made during the potable water recovery subsystem tests.

4.6.2 Subsystem Performance

During the 60-day test, it was found that the "Snap-Tite" seat seal had a tendency to loosen after several uses, and attention was required to maintain proper adjustment for a leakproof closure. Seals at both tissue receptacle covers leaked and were replaced once during the run. Several other leaks were quickly detected and stopped by lubrication of the seals. Three full bags of toilet paper, approximately 2.0 cu ft volume, were collected during the 60-day run.

The slinger unit was used for 47 days; at that time, the slinger motor stalled during use, and was unable to distribute feces. The slinger unit was passed out of the SCS, emptied of 11.5 lb of dried feces, sent back in, and reinstalled. The test crew performed all the inside effort including vacuum line connection without assistance or subsequent adjustment being required. At the conclusion of the run, an additional 2.7 lb of dried feces was removed. The total for 60 days was 14.2 lb.

The diet of the crew was characterized as low to medium residue, and the crew reported less than normal water content in the feces. The slinger unit deposited feces uniformly around the wall for the first 20 days, but by day 30, the distribution was uneven, with a ridge building up in the lower hemisphere below the tines and pockets appearing in the surface. As the surface came closer to the tines, the deposition became less even.

Except for the leaks, the slinger unit operated without malfunction. The crew had no complaints about odor and the only use complaint was that the height from the floor was too great because of the raised seat. The unit was used over 200 times during the 60 days.

4.7 SYSTEM INTEGRATION AND OPERATIONS

The test crew was required to maintain, monitor, and repair the life-support equipment that was installed within the cabin. The atmospheric supply and control subsystem was installed outside because of space limitations. The electrolysis unit of the oxygen recovery subsystem, an interim unit of commercial construction, was also installed outside because this equipment could not function at the 7 psia cabin pressure and was too large for available internal space. In later tests, this unit will be placed by an onboard flight-type unit.

The reliability of the equipment was generally very good; the only major problems were encountered with the new water and oxygen recovery equipment. The history of operation of the life support subsystems during the test was shown in Figure 1.

4.7.1 Repair and Maintenance Requirements

The approach to life-support equipment repair, maintenance, and operation simulated that aboard a space laboratory vehicle. The test crew was trained to complete normal repairs, maintenance, and parts replacement. Standby procedures and units were provided and used until repairs could be completed on the primary unit. All maintenance on inside equipment was accomplished by the test crew with verbal assistance and spare parts, when required, from outside personnel.

A portable TV camera was frequently positioned by the crewmen performing repair or maintenance so that his work could be monitored by outside personnel.

The maintenance operations requiring hardware removal, repair, and replacement during the 60-day test are outlined in Table 26. The crew was also required to perform scheduled maintenance and calibration of equipment as part of the station keeping operation. Many of the tasks performed were not typical of an actual space station operation; therefore, Table 26 also identifies 32 items that might be considered typical of a space station activity. Nonflight qualified prototype life-support equipment was included in the SCS, and required more repair or maintenance effort than fully operational equipment.

4.7.2 Spare Parts Requirements

The spare parts requirements for life-support subsystems and facilities were determined from experience on previous manned tests, failure mode evaluation of new equipment, and vendor recommendations. A list of major life-support spares is shown in Table 27. This list does not include items such as manual valves, instrumentation, fluid fittings, and bulk material (e.g., flexible tubing, wick material, charcoal, molecular sieve, ion exchange resin, and silica gel).

Table 26

SCS 60-DAY TEST--REPAIR AND REPLACEMENT ITEMS (page 1 of 12)

			Equipment Affected		Personnel Ac	
Item	Day	Description of Item	Subsystem *	Facility and Miscellaneous **	Inside	Outside
1	2	A leaking demister tube was replaced in the electrolysis unit H_2 line.	5			X
2Δ	4	The video on TV camera No. 1 became very poor. The camera was removed and passed out for repairs by an outside subcontractor. The portable camera No. 3 was used as a backup system in the exercise area.		1	X	
3Δ	6	A defective intercom amplifier in the command area was replaced.		2	X	
4Δ	8	The repaired TV camera No. 1 was passed in and installed (Reference: Item 2). Operation was satisfactory.		1	X	
5Δ	9	A leaking tube in the raw wash water pump was replaced.	3		X	
6	9	A defective microphone in the emergency intercom system was replaced.		2		X
7Δ	10	A defective time delay relay in the CO_2 concentrator was replaced.	1		X	

Table 26 (page 2 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
8Δ	14	The Astrovac sponge head malfunctioned and was passed out for inspection by outside personnel.		3	X	
		The sponge head was disassembled and blockage was discovered in the water port. The port was cleaned, reassembled, and passed in.				X
		The sponge head was reinstalled and operation was satisfactory.			X	
9	16	The bicycle ergometer overheated and was removed from the chamber for evaluation by outside personnel.		4	X	
10Δ	16	A defective hose on the potable water supply tank was replaced.	2		X	
11	17	The bicycle ergometer was modified by the addition of a cooling fan on the electronic control package and sent back into the chamber (Reference: Item 9).		4		X
12Δ	18	Operation of the three liquid level switches in the urine feed system became erratic. They were removed and passed out for recalibration.	2		X	
		The three level switches were cleaned and calibrated.				X
	19	The liquid level switches were passed in and reinstalled. Operation was satisfactory.			X	

Table 26 (page 3 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
13	21	The pan-and-tilt control on TV monitor No. 2 shorted out. The switch required readjustment and cleaning.		1		X
14Δ	22	The silver-ion generator was removed from the potable water condenser discharge line and replaced by a jumper. The generator had not failed but was removed for evaluation.	2		X	
15Δ	22	A leak in the toilet paper container was corrected by installing a new O-ring seal.	6		X	
16	23	The glass tube in the Sabatier coolant flowmeter broke. The entire flowmeter was removed and passed out for repair in the calibration laboratory.	4		X	
17Δ	23	Two sump screens in the zero-g water separator became clogged and were replaced.	2		X	
18	24	The bicycle ergometer malfunctioned again and was removed from the chamber for evaluation (Reference: Items 9 and 11).		4	X	
19	24	The repaired Sabatier flowmeter was passed in and installed (Reference: Item 18).	4		X	

Table 26 (page 4 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
20	26	The bicycle ergometer was modified by the addition of a blower to the brake mechanism and sent back into the chamber (Reference: Item 18). The operation was now satisfactory.		4		X
21Δ	27	The Sabatier temperature controller failed and was removed.	4		X	
		The spare temperature controller was installed; however, it did not function correctly and was removed for evaluation by outside personnel.			X	
22	29	Power to the dew pointers was lost. The 20-amp fuse in the control box was inspected and appeared to be intact. The control box was removed and passed out for evaluation by outside personnel.		5	X	
		Inspection of the dew pointer control box revealed that the 20-amp fuse, which had been installed in the main power circuit, was only rated for 32 Vdc (should be 125Vac). A 125-Vac, 20-amp, fuse was installed and, to provide additional protection, a 10-amp fuse was added to the sample pump circuit. The modified control box was passed in.				X

Table 26 (page 5 of 12)

Item	Day	Description of Item	Equipment Affected		Personnel Activity	
			Subsystem *	Facility and Miscellaneous **	Inside	Outside
		The control box was installed and operation was satisfactory.			X	
23Δ	29	The light in the air evaporator area burned out and was replaced.		6	X	
24	29	A rectifier diode in the electrolysis unit failed and was replaced.	5			X
25	30	The electrolysis O_2 compressor failed. The two head diaphragms were replaced, and the intake and discharge ball valves cleaned. Operation was normal after rework.	5			X
26	30	The performance of the electrolysis O_2 compressor became marginal after approximately 2 hours of operation. The outlet check valve was replaced with an improved design valve; however, there was no improvement in performance.	5			X
27Δ	31	The zero-g water separator malfunctioned. The differential pressure switch and the three sumps screens were replaced. Operation was normal after rework.	2		X	

Table 26 (page 6 of 12)

[illegible]		Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
	31	The performance of the electrolysis H_2 compressor degraded. The compressor was reworked by cleaning and adjusting the intake and discharge ball valves (Reference: Item 25). Operation was normal after rework.	5			X
29	32	The electrolysis rectifier circuit tripped. Inspection revealed that the cooling air filter was clogged with dirt. After the filter was cleaned and replaced, operation was normal.	5			X
30Δ	32	A redesigned (by AiResearch) Sabatier temperature controller (Reference: Item 21) was installed; however, it again malfunctioned and it was removed for further evaluation by outside personnel.	4		X	
31Δ	32	The CO_2 concentrator vacuum pumps heated and the performance was marginal. The vacuum pump module was removed and passed out for inspection.	1		X	
	33	The two vacuum pumps were disassembled and found to be clogged with molecular sieve dust. They were cleaned, reassembled, and passed in.				X
		The pump module was reinstalled and then functioned normally.			X	

Table 26 (page 7 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
32Δ	33	The outlet silica-gel flow diverter valve did not actuate properly. The actuator and linkage was readjusted to obtain proper operation. It is suspected that the problem was due to valve overheating caused by a normal maintenance bed bakeout cycle, which had just been completed.	1		X	
33Δ	34	The redesigned Sabatier temperature controller (Reference: Item 30) was modified by AiResearch to add a relay and installed again; however, the operation was not satisfactory, and the controller was removed for further evaluation. The Sabatier reactor was put on manual operation.	4		X	
34Δ	36	The molecular sieve bed No. 1 cooling indicator light on the life support monitor began to flicker. During the trouble-shooting procedure, a relay was replaced; however, this did not solve the problem. The problem was traced to a defective switch on the cam timer. Since this switch provided an indicator signal only, it was not replaced.	1		X	

Table 26 (page 8 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
35	37	The performance of the electrolysis H_2 compressor degraded again (Reference: Item 28). The outlet check valve was replaced by an improved design valve as on the O_2 compressor (Reference: Item 26). In addition, an identical check valve was installed on the compressor inlet line; however, although the performance improved, it was still marginal.	5			X
36Δ	40	The redesigned Sabatier temperature controller (Reference: Item 33) was modified by AiResearch to incorporate two relays (for redundancy) and installed. The operation appeared satisfactory; however, manual control was continued, because this mode of operation had been satisfactory for 6 days.	4		X	
37Δ	42	The urine feed pump would not transfer fluid. Inspection of the installation did not uncover the source of the problem, and the pump was removed for evaluation by outside personnel.	2		X	
		The pump was bench tested, found to be satisfactory, and passed in for installation.				X

Table 26 (page 9 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
		Further investigation revealed the problem was caused by blockage in a downstream quick disconnect fitting. The assembly was disassembled, cleaned, and reassembled. The pump operation was satisfactory after rework. The foreign material that caused the blockage was sent out for chemical and microbial analysis.			X	
38	42	The condenser in the Lockheed water separator assembly was replaced. This was a precautionary action only. The old unit had not failed visibly but was suspected of a possible Coolanol leak into the condensate water. Subsequent testing did not show signs of leakage.	2		X	
39Δ	45	The urine feed pump would not transfer fluid. Inspection revealed blockage in the disconnect again (Reference: Item 37). The blockage was removed and the pump operation was satisfactory.	2		X	

Table 26 (page 10 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
40	46	The electrolysis H_2 compressor thermal overload tripped. Inspection revealed that the compressor had jammed due to a broken oil guide on the compressor shaft. In addition, inspection of the O_2 compressor revealed the same failure in this unit as well as a rupture of the head diaphragm. Both units were removed and sent to plant maintenance for repair. Since all spare parts had been expended, new parts were ordered from the vendor.	5			X
41Δ	47	A leak in the wash-water raw-tank sight gage was repaired by repositioning the gage.	3		X	
42	47	The tines in the waste management collector jammed due to excess dried fecal material. The complete assembly was removed from the chamber.	6		X	
		The collector was cleaned, checked out, and sent back into the chamber.				X
		The waste management subsystem was reassembled and operation was satisfactory.			X	
43Δ	48	TV camera No. 2 failed and was passed out for repairs by an outside subcontractor. Portable camera No. 3 was used as a backup system in the command area.		1	X	

Table 26 (page 11 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
44Δ	49	The gas flow through the thermal conditioning heat exchanger was noted to be down to approximately 900 cfm (should be 1,200 cfm). The inlet filter was checked, found to be clogged with dust, and removed. Without the filter, the flow increased to 1,600 cfm, and the cabin temperature decreased several degrees; therefore, a clean filter was not installed for the remainder of the run.	7		X	
45Δ	50	The repaired TV camera No. 2 was passed in and installed (Reference: Item 43); however, the picture was not sharp and would not stay in sync.		1	X	
46Δ	50	The silver-ion generator, which was removed on the 22nd day (Reference: Item 14), was reinstalled.	2		X	
47Δ	51	The zero-g water separator malfunctioned again (Reference: Item 27). The switch and 3 sumps were replaced and operation was normal after rework.	2		X	
48Δ	51	The wash water circulation pump malfunctioned and was repaired.	3		X	

Table 26 (page 12 of 12)

Item	Day	Description of Item	Equipment Affected: Subsystem *	Equipment Affected: Facility and Miscellaneous **	Personnel Activity: Inside	Personnel Activity: Outside
49Δ	51	TV camera No. 2 continued to malfunction (Reference: Item 45) and it was removed again. The portable camera No. 3 was installed as a backup system.		1	X	
50	52	The repairs on the electrolysis H_2 and O_2 compressors were completed (Reference: Item 40). Both compressors were installed and operation was satisfactory.	5			X
51Δ	54	A leaking tube in the raw wash water pump was replaced again (Reference: Item 5).	3		X	
52Δ	57	The repaired TV camera No. 2 was sent back into the chamber and installed (Reference: Item 49). Operation was satisfactory.		1	X	

*Subsystem Code:

1 - CO_2 Concentrator
2 - Potable Water Reclamation
3 - Wash Water Recovery
4 - Sabatier Reactor
5 - Electrolysis
6 - Waste Management
7 - Thermal Control

**Facility and Miscellaneous Code:

1 - TV Monitoring
2 - Intercom
3 - Astrovac
4 - Bicycle Ergometer
5 - Dew Pointer Instal
6 - Chamber Lighting

Δ Item considered typical of actual space station activity.

Table 27

MAJOR SPARES REQUIRED FOR 60-DAY SCS TEST (page 1 of 6)

Subsystem	Spare Part	Part No.	Vendor	Number Stocked	Remarks
CO_2 Concentrator	Heat Exchanger	47D21	Janitrol	1	
	Condenser	8406-F	Stewart-Warner	1	
	Valve	3NC90RX	Bellows-Valvair	1	
	Solenoid Valve	KLC-33E	Bellows-Valvair	3	
	Solenoid Valve	8320107	ASCO	2	
	Valve Kit	5-1265-1	Republic	4	
	Vacuum Pump	08-423-71	Air Control	-	Not spared since two pumps were installed for redundancy. Cleaning required after 32 days of operation.
	Actuator	8BR-WP	RAMCON	3	One required adjustment on day 33.
	Cam Timer	Mod. 8, Series MC	Industrial Timer	2	A microswitch malfunction noted on days 3 and 36. Replacement not deemed necessary, because switch provided monitoring signal only.

Table 27 (page 2 of 6)

Subsystem	Spare Part	Part No.	Vendor	Number Stocked	Remarks
	Relay	CHB-38-70003	Potter and Brumfield	1	One failed on day 10.
	Relay	CHB-38-70013	Potter and Brumfield	1	
	Relay	BOHRO-6A	Allied	6	One replaced on day 36 while trouble-shooting the micro-switch malfunction; however, part had not failed.
	Relay	900-2C	Guardian	6	
	Circuit Breaker	AM12-6-250-60-4	Heinemann	1	
	Circuit Breaker	AM333-2-250-400-15	Heinemann	1	
Potable and Wash Water Recovery	Blower	5000702-2484	Joy	1	
	Condenser	8481A	Stewart-Warner	1	Replaced on day 42 as precautionary action only. No failure.
	Condenser	47D20	Janitrol	1	
	Solenoid Valve	B2DA9175	Skinner	1	
	Pump	7022	Cole-Parmer	3	The raw wash water pump required replacement of the flexible tube on days 9 and 54.
	Pump	7020V-15	Cole-Parmer	1	

Table 27 (page 3 of 6)

Subsystem	Spare Part	Part No.	Vendor	Number Stocked	Remarks
	Pump	Model IP677	Teel	2	The wash water circulation pump impeller malfunctioned on day 51 and was repaired.
	Pump	D-11-1	Eastern	1	
	Pump	3J34D-316	Eastern	1	
	Pump	8027	Micropump	1	
	Heater	ARTM-1500L	Cromalox	3	
	Heater	SEF-100	Cromalox	3	
	Pressure Switch	RD12613DR34	Pall	2	Replaced on days 31 and 51.
	Sump Screen	R71640-503	Lockheed	3	The three installed sumps were cleaned on days 31 and 51.
	Filter	91185	MSA	1	
	Filter	MCS1001EE	Pall	3	
	Filter	ACF4463UR	Pall	15	
	Filter	MCS1001EC	Pall	3	
	Filter	MCY1001URA	Pall	10	
	Pump Controller	7020C	Cole-Parmer	1	

Table 27 (page 4 of 6)

Subsystem	Spare Part	Part No.	Vendor	Number Stocked	Remarks
	Electronic Liquid Lever Control	--	Douglas Fab.	3	The three controls in the urine feed system were cleaned and adjusted on day 18.
	Relay	BOHRO-6A	Allied	6	
	Relay	GA17A	Potter and Brumfield	2	
	Relay	PM17AY	Potter and Brumfield	1	
	Relay	2200U-DPDT	Guardian	1	
	Circuit Breaker	AM333-3-250-400-14	Heinemann	1	
Thermal and Humidity Control	Blower	X702-313A	Joy	1	
	Blower Motor	906D073-1	Westinghouse	1	
	Heat Exchanger	47D19	Janitrol	1	
	Heat Exchanger	50D34	Janitrol	1	
	Condenser	47D20	Janitrol	1	
	Circuit Breaker	7276-1-2	Klixon	1	
	Circuit Breaker	7276-1-10	Klixon	1	
Atmospheric Supply and Control	Power Supply	Model 1020	EICO	1	
	Amplifier	DY2460A	Dymec	1	
	O_2 Analyzer	Model 778	Beckman	1	
	O_2 Sensor	145165	Beckman	2	

Table 27 (page 5 of 6)

Subsystem	Spare Part	Part No.	Vendor	Number Stocked	Remarks
Toxin Control	Blower	19A894	Globe	1	
	Sorbent Bed	D-SK-1743-311	MSA	1	
	Catalytic Bed	D-SK-1743-331	MSA	1	
	Filter	D-SK-1743-311	MSA	1	
	Heater	D-SK-1743-326	MSA	2	
	Rheostat	Type R-100	Tru-Ohm	1	
	Circuit Breaker	MS21984-5		1	
Thermal Conditioning	Pump	H124TW	Viking	1	
	Pump	H497	Viking	1	
	Heater	TMO-615B	Cromalox	1	
	Solenoid Valve	8315A22U	ASCO	1	
	Modulating Valve	VP2024-103-1-2	Barber-Coleman	1	
O_2 Recovery (Sabatier)	Blower Motor	906D073-1	Westinghouse	1	
	Solenoid Valve	K3AB542	General Control	*	
	Solenoid Valve	2110-6011-3/8	Hayes	*	
	Solenoid Valve	L2DR4150	Skinner	1	
	Control Valve	133514-1	AiResearch	*	
	Pump Kit	SK92	Jabsco	1	
	Heater	R-1847	Rama	*	

*Not stocked. Immediately available from subcontractor.

Table 27 (page 6 of 6)

Subsystem	Spare Part	Part No.	Vendor	Number Stocked	Remarks
	Temp. Controller	TC121R	Harrel	*	Original unit and spare malfunctioned. System operated on manual for last 26 days.
	Relay	BOHRO-6A	Allied	2	
	Circuit Breaker	SM333-4-250-400-58	Heinemann	1	
O_2 Recovery (Electrolysis)	Compressor Spare Part Kit	*(Model 154C)*	Kemlon	1	The O_2 compressor failed on day 30, and the H_2 compressor failed on day 31. After repair, performance was marginal and both failed again on day 46.
	Relay Coil	15D21GR2	General Electric	1	
	Relay Coil	69A86	Allen-Bradley	1	
	Relay Coil	84A86	Allen-Bradley	1	
	Main Diode	1N4044		2	
	Diode	367H		1	One failed on day 29.
	Fuse	FNA3	Bussman	3	Blew on day 29 when diode failed.
	Main Fuse	A13X250	Chase Shawmut	2	
	Trigger Fuse	T-I-130	Chase Shawmut	4	

*Not stocked. Immediately available from subcontractor.

The spare parts that were stocked were sufficient to support the 60-day test except for the spare parts that were required for the electrolysis unit compressors. On day 46, both compressors failed for the second time and, because the spares provided originally by the vendor had been used, additional parts had to be ordered. Repairs could not be completed until day 52. Since the unit was an interim commercial model, these failures were not representative of a flight-type unit.

Section 5
CHECKOUT PROCEDURES

This section presents a brief summary of the subsystem and system preflight checkout, procedures, emergency dry runs, and the five-day checkout test. These items were required to accomplish the man-rating of the SCS per References 5 and 13, ensure proper operation of all equipment, and provide training for the operating crew and test subjects.

5.1 SUBSYSTEM CHECKOUT

The subsystems which were basically unchanged from previous manned tests were refurbished and checkout out during the facility preflight checkout and 5-day checkout tests. Extensive bench testing was conducted on new and redesigned components of the oxygen and water recovery subsystems as well as the redesigned carbon dioxide concentrator subsystem.

5.1.1 Oxygen Recovery Subsystem

Bench and acceptance testing of the Sabatier unit was conducted by the manufacturer prior to delivery to McDonnell Douglas. After installation into the SCS, the Sabatier unit was operated for approximately 30 hours prior to the 5-day test. Instrumentation adjustments were made as a result of this 30-hour subsystem test. During the 5-day checkout test, it was noted that excessive voltage drop or line resistance caused inaccuracy in the Sabatier reactor temperature alarm circuit. Large wires were installed after the 5-day test to reduce this voltage loss.

The water electrolysis unit and the related components were operated for 28 days prior to the start of the 5-day checkout test.

5.1.2 Potable Water Recovery Subsystem

Prior to the construction of the potable water recovery subsystem used in the 60-day tests, a breadboard unit was operated during 1,020 hours of development tests, and more than 1,400 pounds of urine was processed. These tests established the method of urine feed control and the detail design of the wick evaporator packages, the urine distributor manifold, the air charcoal bed including the type of charcoal, the postfiltration module, and the thermal storage and water dispensing units. During these tests, baseline chemical and microbial data were obtained.

Based on the information obtained in the bench tests, the subsystem used in the 60-day run was designed, constructed and installed in the SCS. This subsystem was operated for 432 hours prior to the 5-day checkout run of the SCS. During this time, 324 pounds of urine were processed, and a medically monitored double blind potability test was conducted in which the four crew members and four staff members participated.

Immediately following these tests, the 5-day checkout run was conducted during which 17 pounds of urine was processed and the two crew members who had been drinking reclaimed water in the double blind tests continued to do so.

After the completion of the 5-day checkout test, the subsystem was modified to install a silver-ion generator downstream of the water condenser/separator. This generator was installed to permit an evaluation of this unit's ability to inhibit microbial growth in the multifiltration unit. In addition, a flowmeter was installed to measure the flow rate of the Coolanol 35 flowing to the water chiller near the cabin sink.

5. 1. 3 Wash Water Recovery Subsystem

A 60-day bench test was conducted on the wash water subsystem prior to installation into the SCS. After installation into the SCS, the subsystem was steam sterilized, leak checked and final sterility tests performed.

An impeller failure occurred in the sink pump during the 5-day checkout test. A new rubber impeller was passed into the SCS and was installed by the crewmen. The new impeller and the pump functioned satisfactorily for the remainder of the 5-day test. To ensure satisfactory draining of the sink during the 60-day test, a quieter, more reliable sink pump with stainless steel impeller was installed after the 5-day checkout test.

5. 1. 4 Carbon Dioxide Concentrator Subsystem

Bench testing was performed on the carbon dioxide concentrator unit vacuum pump module. Carbon dioxide concentrator adjustments and operational tests were conducted after installation into the SCS was completed. Instrumentation calibration and adjustments were made on all gages and flow indicators at sea level and altitude conditions.

Because of very severe transient and reverse flow conditions during bed cycling, the mass flow transducer measuring the cabin discharge flow from the molecular sieve beds and the float for the rotameter downstream of this mass flow transducer were removed after the 5-day checkout test. In addition, the signal conditioner and the readout device of the subject mass flow transducer were removed from the Life Support Monitor Console outside of the SCS. Total subsystem gas flow rates were obtained from the inlet flow transducer and the silica gel desorbtion flow rotameter during the 60-day test.

5. 2 PREFLIGHT CHECKOUT

Prior to the start of the 5-day and the 60-day manned tests, a thorough visual inspection and operational checkout was accomplished on all facility systems, each piece of emergency equipment, and all other equipment of which proper operation could be vital to the health and safety of the crewmen.

These facility checkouts included a current status verification of all maintenance and calibration requirements and were performed per the detailed instructions of the Preflight Inspection section of the SCS Facilities Operating Manual. The Preflight Inspection section was prepared with emphasis on inspection and performance of equipment and systems to detect any existing or impending degradation of performance by monitoring critical parameters and the subsequent relationship to the health and safety of the crewmen inside the SCS.

Items that were inspected and checked out during the preflight inspection included the gas analyzer system, the atmospheric supply control subsystem, the carbon dioxide concentrator subsystem, the outside hot and cold water systems, the hot and cold Coolant 35 systems, the closed-circuit television system, the intercom system, the vacuum pumps (main and auxiliary), the vacuum controls, the SCS pressure indicators and controllers, the pneumatic supply system, the SCS overpressurization relief valve, the pass-through ports and airlock doors, safety lights and latches, electrical power circuits, the inside power emergency shutoff switch, emergency lights (inside and outside), the emergency nitrogen repressurization system, the emergency water spray system, the emergency shower, the emergency oxygen system, the emergency intercom, the emergency hot-line phone, the warning siren and bell, the smoke-detection system, the carbon dioxide fire extinguisher system, air packs, pocket respirators, the emergency abort system, and rescue equipment.

After the preceding checkout was completed at sea-level conditions, the SCS atmosphere was reduced to a pressure of 362 mm Hg abs (7 psia) and the operational capability of all vacuum controls was demonstrated. At the conclusion of this test period, the SCS was returned to sea-level pressure using the Emergency Abort Procedure with the water spray system inactive. For this portion of the checkout, soft aluminum foil streamers 0.003 in. thick, 1.5 in. wide, and 5 ft long were suspended from the cabin ceiling beneath the cabin flood inlet port and in the areas adjacent to the GN_2 repressurization nozzles. These streamers were observed through the viewports during repressurization, and no extreme streamer movement was noted. The time required to return to sea-level pressure was 35 sec, measured from the receipt of the emergency abort alarm to the point at which the SCS door was actually opened.

Following the completion of all preflight inspections, checkouts, dry runs, crew indoctrination, and training, the test atmosphere was attained within the SCS (between 155 and 160 mm Hg partial pressure of oxygen, with nitrogen diluent added to make up a total pressure of 362 mm Hg absolute), and satisfactory operation of the facility and all subsystems was demonstrated for approximately 4 hours.

During this 4-hour altitude test, the subsystems within the SCS were operated at a simulated altitude of 19,200 ft, with a total cabin pressure of approximately 362 mm Hg. Two engineers and one technician were inside the SCS during this performance test. The test served to man-rate the SCS and allowed for adjustment of the controls and calibration of the gages of the subsystems at the operating cabin pressure and atmosphere. During this test, sound levels were measured and recorded at various locations within the SCS and complete subsystem instrumentation readings were made. Table 28 lists the ranges of sound levels measured.

5.3 EMERGENCY DRY RUN

Prior to the start of the 5-day and 60-day manned tests, dry runs were accomplished on all emergency procedures with inside and outside crews to ensure proper sequencing and complete coverage of all task assignments. In addition, each crew member actually practiced extinguishing oil fires with carbon dioxide extinguishing equipment under the direction of Fire Services personnel.

Table 28

SOUND LEVELS RECORDED DURING SCS SUBSYSTEM ALTITUDE CHECKOUT

SCS Area	Sound Level Range (decibels)	Notes
Kitchen	76-83	Microphone located on counter, approximately 5 feet from floor
Command	73-81	Microphone located on counter, approximately 3 feet from floor
Bunk*	74-77	Microphone located in upper bunk with curtain closed
Exercise	74-79	Microphone held in vertical position approximately 5 feet from the floor
Waste management	73-78	Microphone held in vertical position approximately 5 feet from the floor.

*A heavy beta-cloth curtain was installed and the walls painted with acoustic paint after the 5-day test. Later sound measurements indicated an average sound level reading in the bunk area to be less than 74 decibels.

During the 5-day test, emergency abort dry runs were performed by each outside crew at least once during each shift. These dry runs were performed to the extent possible without actually changing the environment within the cabin or airlock, without leaving the main control console unmanned and without affecting in any other way the status of the test or safety of the crew within the SCS. As part of the dry run, each member of the outside crews, except the medical monitor, practiced donning the rescue equipment (boots, coat, air pack, helmet, and gloves).

5.4 FIVE-DAY CHECKOUT TEST

A 5-day manned checkout test was conducted to refine the SCS operational procedures. Calculations were made based on data from inside the outside instrumentation to verify that the performance of each subsystem was at the specified design level. A special log was kept on subsystems and equipment which required repair and/or modifications before the 60-day test.

No major problems were encountered during the 5-day manned checkout test. However, there was a need for minor additions, improvements, and/or modifications to several subsystem components in the SCS. The more important changes which were made as a result of the 5-day manned checkout test were detailed in Subsection 5.1, Subsystem Checkout.

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Section 6

CONCLUSIONS

The completion of the 60-day test provided information that will be useful in the development of future spacecraft life support systems. This section contains a discussion of conclusions that may be drawn from the 60-day test results.

Since most of the life support system equipment was installed within the cabin and the test crew was required to maintain, monitor, and repair this equipment, the test provided an opportunity to evaluate repair and maintenance requirements under realistic conditions. During the 60-day test, there were 32 items of repair and replacement that could be classified as typical of an actual space station operation. These items, as well as normal scheduled maintenance, were all performed by the test crew without jeopardizing the test mission objectives. The lack of major problems is significant, since much of the prototype hardware included in this test was not designed for aerospace reliability requirements.

6.1 ATMOSPHERE SUPPLY AND PRESSURIZATION

Performance of the Sabatier reactor was, in general, very successful. Conversion efficiencies of 90 to 93 percent were achieved. The only operational problem was the failure of a solid-state temperature controller. Manual control of bed temperature was necessary after efforts failed to provide an acceptable substitute control. This enabled satisfactory completion of test requirements. The catalyst (nickel on kieselguhr) showed no visible signs of deterioration upon test completion.

The gases produced by the water electrolysis unit were satisfactory from a purity and quality standpoint. The reliability of the unit, however, was very poor, with repeated failures of gas compressors. This unit is an industrial model, not representative of a flight-type unit, and will be replaced with an improved onboard unit for future tests.

The two-gas atmospheric control subsystem operated without problems throughout the test. The polarographic sensor provided adequate control over the oxygen partial pressure at all times while it was in the control loop. Its use as a controller was discontinued after day 14 to permit evaluation of the mass spectrometer as a control element.

The mass spectrometer can be used effectively to measure quantities of at least four gas constituents within the SCS, in addition to providing signals for the control of oxygen partial pressure and cabin total pressure. It appeared to offer good reliability (the only downtime resulted from a defective belt on the vacuum pump), but frequent calibration was required. The mass spectrometer indicated an oxygen partial pressure averaging between 4 and 5 mm Hg higher than the Beckman paramagnetic sensor.

6.2 WATER MANAGEMENT

The open-cycle air evaporation technique is a feasible means for reclaiming potable water from urine and humidity condensate. The system furnished sufficient potable water to provide for crew and sampling requirements. Improvements that would have enhanced the performance are concluded to be in the following areas:

1. Improved measurement accuracy in injecting the pretreatment chemical in each urine batch.
2. Control or elimination of mold growth in the stagnant urine.
3. Capability for sterilization of bacterial filters without removal.

These problems did not interfere with the successful production of water that met rigid potability standards.

The zero-g water condenser/separator proved efficient and relatively trouble free throughout the 60-day test. It can be concluded, based upon the unit performance, that improvement should be sought in the area of subassembly reliability (e.g., pressure switches). The hydrophilic sump filters plugged several times, suggesting that larger capacity should be provided for particle accumulation without plugging.

The silver-ion generator appears to have contributed to longer periods without bacterial contamination of the filters in the potable water subsystem. It was especially effective in inhibiting bacterial growth immediately downstream, but was less effective at a distance from its location. Two theories were proposed for explaining this loss in effectiveness: (1) silver plated out on metal surfaces an/or (2) a constituent of the water reduced the ionic silver to metallic form. Further tests are needed to determine if one or both processes accounted for the loss of silver ions.

The general feasibility of the basic multifiltration design for treatment of wash water was proved by the successful removal of organic and inorganic materials during the 60-day test period. System improvement, however, could be made in the following areas:

1. Improved means of prolonging microbial filter effectiveness.
2. More accurate control of minimum BAK concentration.
3. Improved reliability in sterilization of the water distribution and return loop.
4. Methods to accommodate food residue without contaminating the system.

6.3 ATMOSPHERE PURIFICATION AND CONTROL

The upgraded carbon dioxide concentrator subsystem performed very well through the test and required only minimum maintenance. The SCS atmosphere average carbon dioxide partial pressure level was maintained below

4 mm Hg. The most severe problem encountered during the test was generation and migration of molecular sieve dust through the system. This had not been noticed in previous tests and was apparently due to severe pressure transients that occurred during changes in molecular sieve beds between adsorption and desorption modes. The new valves, installed to prevent leakage during bed desorption, were much quicker acting than those previously used and were responsible for these transients.

Control of trace contaminants was accomplished by the toxin control subsystem, which performed without problems. Its effectiveness was proved at two different times during the test by checking the levels of carbon monoxide with it operating and after it had been shut down for several days. Tests showed a continued rise in carbon monoxide levels when the toxin control subsystem was not operating.

The aerosol particle sampler and analyzer appeared very useful in determining purity of the space cabin atmosphere. Results indicate the particle count was markedly lower in the SCS than that in the environment immediately outside. The measured particle concentrations also indicate a very gradual decline in the number of particles existing in the closed space cabin over a long period of time.

6.4 THERMAL AND HUMIDITY CONTROL

The operation and reliability of the thermal control subsystem was satisfactory. The humidity control system was not operated since cabin humidity was removed by the open cycle water recovery subsystem throughout the 60-day test. The only problem encountered was plugging of the cabin air filter by dust which restricted flow and reduced cooling capacity. The capacity of the thermal control subsystem was marginal due to the increased heat load introduced by the new water and oxygen recovery equipment. Cabin temperature was maintained slightly above normal values, at 77° to 80°F, but crew comfort was adequate because a low relative humidity (30 percent) was achieved by the operation of the open cycle water recovery subsystem as well as by the humidity condensate removed by the thermal control heat exchanger and silica gel desorbate condenser.

6.5 WASTE MANAGEMENT

The slinger-type waste management subsystem maintained very good odor and bacterial control in the cabin during the test. After replacement of the zero-g seat (at the end of the 5-day test) with a standard hinged toilet seat (compatible with the 1-g environment of test), the crew members found the subsystem very satisfactory. A minor problem was experienced several times during the test with the "Snap-Tite" plug as a result of leaking to space vacuum after use. If care was exercised at each time of use to obtain complete sealing, no leakage occurred.

Section 7
RECOMMENDATIONS

The primary objective of this test was the operation of the environmental control and life support systems for the 60-day period. The recommendation for the system improvements that result from a test such as this are very important with respect to system designs and future tests. The following recommendations are based on observations and system performance results.

7.1 SOUND LEVEL

Acoustic measurements revealed that the sound level was approximately 80 decibels inside the chamber during the 60-day test. Although this level is comparable to that of existing spacecraft, this sound level began to irritate the crewmen in the last week of the test (Reference 1), and must be reduced for the longer missions. Since the major source of this high sound level is the small high-speed blowers and other dynamic equipment used in the chamber, the life support equipment must be upgraded to replace the present blowers with quieter units wherever feasible. If replacement is not possible, blowers and other dynamic equipment must be isolated from the crew living quarters. In addition, acoustical material must be added to the chamber compartment walls and ducting.

7.2 ATMOSPHERE SUPPLY AND PRESSURIZATION

The Sabatier reactor performance indicates that adequate reactor temperature control can be maintained with a manually controlled cooling gas flow valve. The present solid-state temperature controller should be replaced with a simple manual control incorporating a temperature monitoring and alarm system. In addition, development bench test should be conducted to evaluate reactor performance with other catalysts such as ruthenium.

The commercial water electrolysis unit must be replaced with a flight-type onboard unit. The availability of this type of unit would permit a true system evaluation and more efficient modes of operation than was possible with the commercial unit.

7.3 WATER MANAGEMENT

The open-cycle air evaporation method for reclaiming potable water from urine and humidity condensate is highly feasible based on the test results. The following recommendations are made to improve the design:

1. Install an automatic chemical pretreatment dispenser to ensure injection of the proper amount of chemical.
2. Investigate the direct injection of each urination into the wick evaporator instead of in 1-liter batches. The urination records showed that there was sufficient time lapse between batches to allow the wick package to dry out and therefore the concept of

maintaining the package moist to prevent volatile organics from being driven into the water was negated. The new approach would eliminate one pump and the electronic liquid level control system. It might also prevent the mold growth problems caused by stagnant urine in the holding tank.

3. Reduce the size and number of wick packages. Examination of the used wicks indicated that only half of each package was used to retain the urine solids, and only three of the six wicks were fully used. Each wick would have lasted longer had the proper amount of urine pretreatment been used, because the criteria for changing wicks was the detection ammonia odors in the cabin. The purpose of pretreatment was to prevent formation of ammonia.

4. The carbon dioxide concentrator silica gel condensate should be fed to the wick evaporator rather than fed directly to the multifiltration portion of the system. This might increase the life of each wick package by reducing the concentration of urine solids, thereby preventing premature termination of wick usage because of ammonia odor. It would also reduce the organic load on the multifiltration unit.

5. The multifiltration unit should be improved by providing more efficient bacterial filters and in-line flow charcoal and ion-exchange columns to increase their effectiveress. Also, the bacterial filters could be provided with a means for onboard sterilization or some means of significantly prolonging filter sterility. A solution to this onboard sterilization problem is very important since the techniques developed could be applied to water recovery systems other than air evaporation.

6. The size of the 4 potable hot-water tanks could be reduced so that each tank will accommodate one day's supply instead of two. This would reduce the space requirement, and also the power consumed to maintain the water temperature at 160°F. The continued use of 4 tanks will still provide sufficient reserve to allow potability analysis of the water.

7. Water flow totalizers and additional instrumentation to provide more accurate water balance data should be installed.

8. Install an automatic benzalkonium chloride (BAK) dispenser at the sink water supply outlet. Microbial control within the wash water recovery subsystem could not be maintained since the BAK concentration was not maintained at the required concentration of 500 ppm. It is suspected that the BAK concentration was also diluted by coprecipitation with food particles which entered the system from the sink drain.

9. Further testing and evaluation is required to determine a neans to accommodate residual food particles and other contaminants in the wash water system. The open-cycle air evaporation unit might be sized to process the wash water as well as the urine and humidity condensate, if satisfactory reclamation of wash water by multifiltration alone is not found to be feasible.

7.4 CARBON DIOXIDE CONCENTRATOR

This subsystem which had been upgraded prior to the 60-day test, contained new quick-acting selector valves to prevent leakage into the molecular sieve beds during desorption. However, these valves caused severe pressure transients during changes in molecular sieve beds between adsorption and desorption. A small, automatically controlled bleed valve with a manual override should be added to the molecular sieve module to eliminate the rapid repressurization of the evacuated canister, which apparently caused the dusting of the molecular sieve material that contaminated much of the system.

7.5 THERMAL CONTROL

The thermal control subsystem operated satisfactorily during the test, but the following improvements would greatly increase its efficiency:

1. Increase the size of the heat exchanger and distribution ducting to reduce air velocity and noise level.
2. Reduce condensation on the coil surfaces by installing a temperature control capable of maintaining the coolant temperature above the cabin dewpoint.
3. Insulate the distribution duct to increase efficiency.
4. Increase the number of diffusers to improve air distribution.

7.6 FACILITIES

The following recommendations on the facility support equipment would increase the efficiency of the SCS operation:

1. Install a new intercom system that would incorporate:
   - External and internal speakers located at each intercommunication station. This would eliminate the need for constant wearing of a headset and increase mobility.
   - Lightweight microphones and headsets which are more comfortable and less cumbersome than the present units.
2. New TV monitors should be installed to improve picture quality and reliability of observations. Fixed TV cameras with wide-angle lenses should improve area coverage, and eliminate sensitivity of the test subjects to "tracking" by the remote pan-and-tilt operation of the present cameras.
3. Enclose the test conductor's console and monitor's stations to provide a control room atmosphere. The enclosures should be sound-proofed and air-conditioned. This would greatly improve the operating crew's efficiency. A separate cubical within the enclosure should also be provided for use by the medical monitor and anyone requiring private conversation with the crew.

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Appendix A
DESCRIPTION OF TEST FACILITY

This section presents a description of the McDonnell Douglas Space Cabin Simulator (SCS), the support facilities, and the related facilities used during the 60-day manned test of the Space Cabin Simulator.

A. 1 SPACE CABIN SIMULATOR (SCS)

The SCS, located in the Biotechnology Laboratory of the McDonnell Douglas Astronautics Company in Santa Monica, California, was designed to provide operating experience with life-support systems for manned spacecraft. Following the initial operation in December 1964, and prior to the 5-day checkout and 60-day test reported herein, the SCS was operated for 78 days of manned testing. The SCS is a double-walled steel cylinder 12 ft in diameter by 40 ft long, with an empty volume of 4, 100 cu ft. The annular space between the inner and outer chamber walls is normally evacuated slightly below cabin pressure to ensure that all leakage is outward and to provide realistic testing of environmental control and life-support systems. To minimize heat loss, the entire external structure is insulated with semi-rigid rockwood insulation (Johns-Mannsville Spintex No. 414) and is covered with white canvas. Figure A-1 shows the general internal arrangement of the simulator, including major equipment items of the life-support system.

The chamber interior orientations were designated as forward (facing the Command Center) and aft, with right and left specified when facing forward. The airlock at the aft end of the SCS is used as the entrance and exit for the chamber. Two pass-through ports are located on the right side of the SCS. These ports were used for transfer of samples, data sheets, mail, food resupplies, spare parts, etc. into and out of the chamber during the test. Seven view ports are provided on the right and left walls, one on the forward bulkhead, and one on each of the two airlock doors. These plexiglass view ports are coated to produce a one-way mirror, permitting viewing from the exterior to the interior but not from the interior to the exterior. Other ports are installed in various positions around the chamber walls to provide access through the double wall for instrumentation, electric power, and plumbing for gases and liquids. The inner and outer shells, the airlock, the pass-through ports, and other supporting structures are designed to withstand a differential pressure of 15 psi from either side.

The arrangement of SCS control consoles is shown in Figure A-2. The cabin and the airlock are interconnected to five high-capacity vacuum pumps. Manual and pneumatic valves are arranged at the main console to control the cabin pressure, annulus pressure, and cabin venting. The airlock pressure is controlled with manual valves at the airlock console. Vacuum on the inner and outer airlock door seals is maintained through a low-volume vacuum pump. The vacuum controls for the pass-through ports are manually operated, and are maintained by small vacuum pumps. When not in use, the pass-through ports are connected to the annulus.

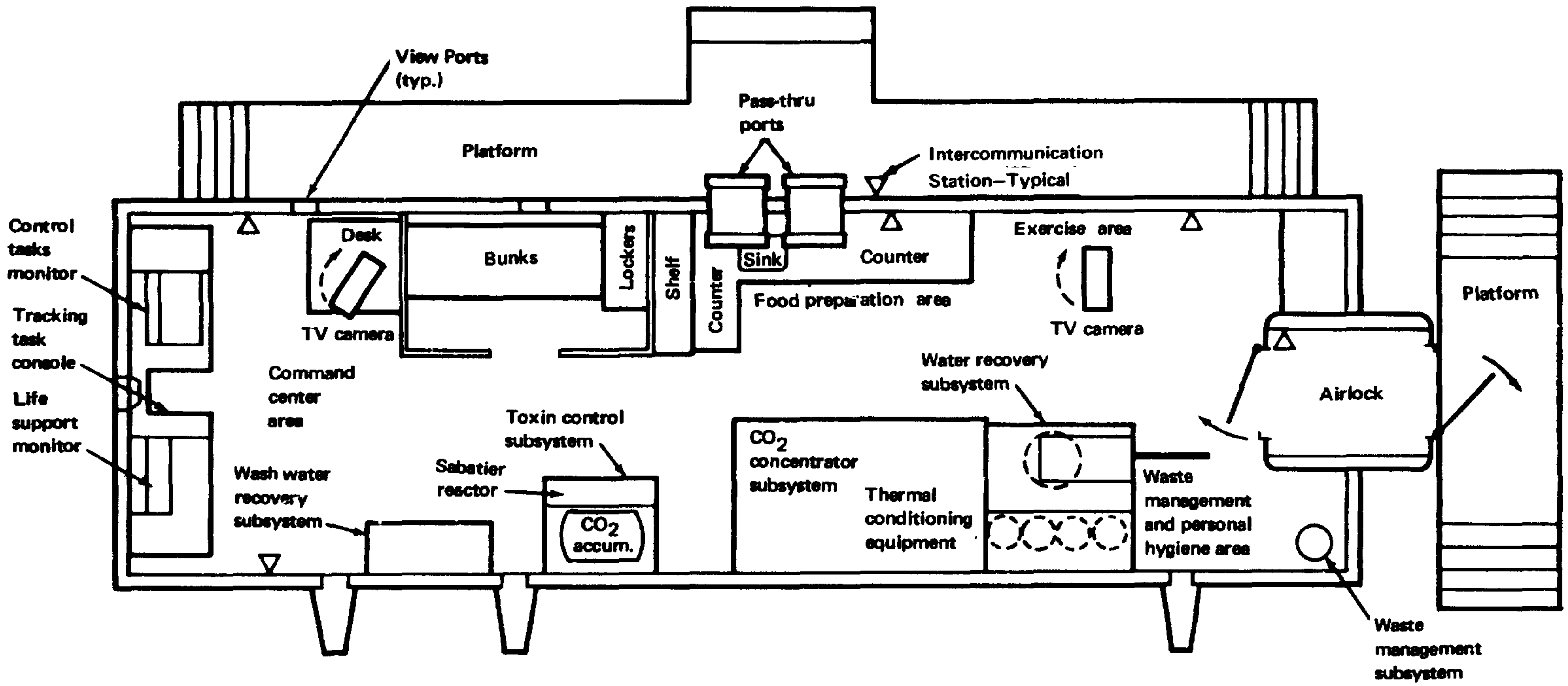


Figure A-1. General Internal Arrangement

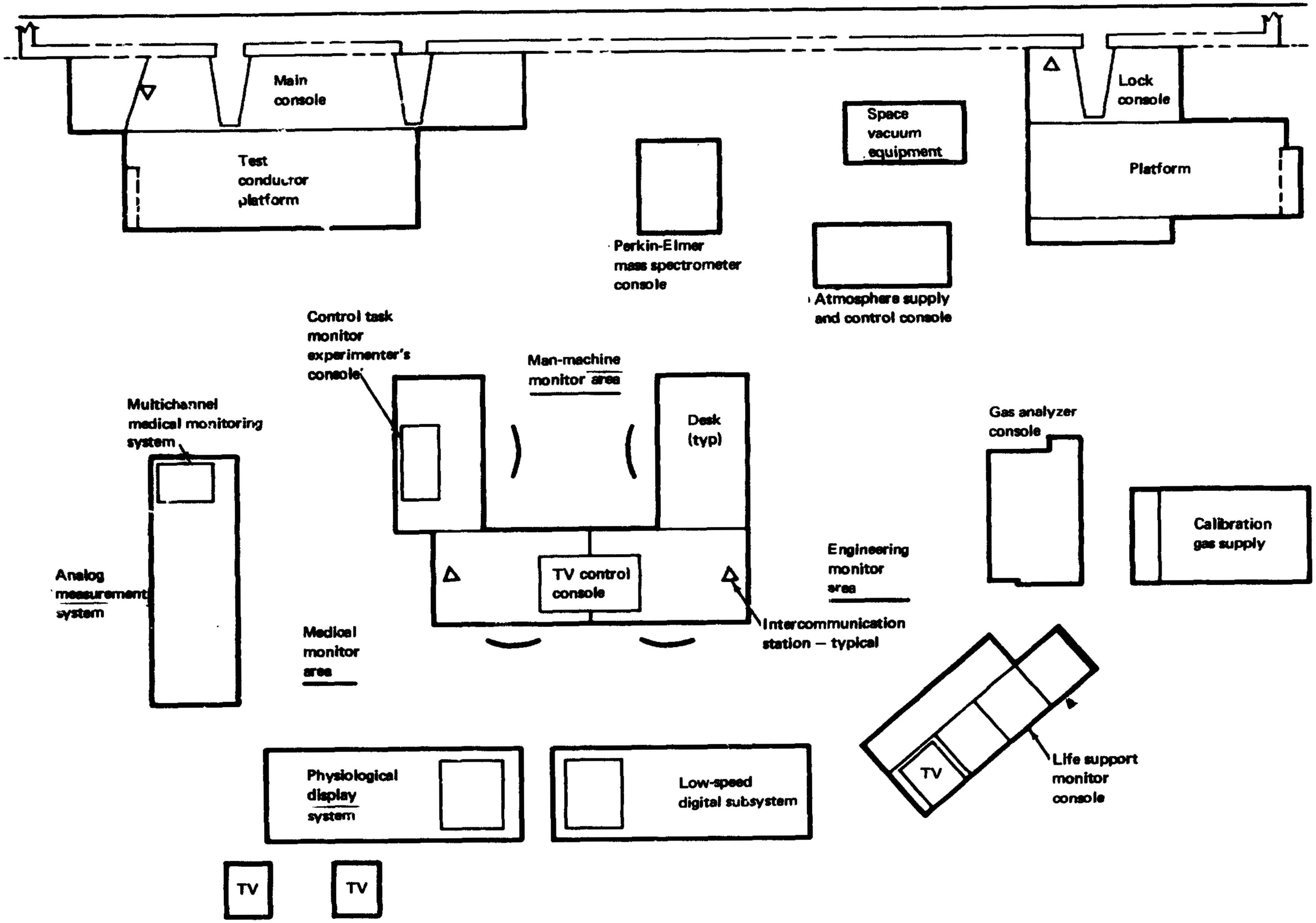


Figure A-2. Outside Monitoring Area for the SCS

A. 1. 1 Airlock

The airlock is located at the aft end of the SCS, as seen in Figure A-1 and A-3. It is 4 ft wide, 7 ft high, and 5 ft 4 in. long, with a volume of about 150 cu ft. Two doors are provided; an outer door, hinged to swing out from the airlock and an inner door, hinged to swing into the cabin from the airlock. Both door openings are 3 ft wide and 6 ft high. Each door is provided with a 10-in. diameter view port and a door latching mechanism that can be operated from either side of the door. A double neoprene seal is used on each door and a method is provided to independently control the pressure between the two seals with the door in the closed position. Four standard aircraft-type oxygen breathing regulators are installed within the airlock to provide either diluted or 100% oxygen, as selected, at simulated altitudes. Overhead lighting and an intercom outlet for earphones and microphones are also provided.

A. 1. 2 Pass-Through Ports

Two identical pass-through ports are located above the sink in the food management area. The pass-through ports can be seen in Figure A-4. These ports are 18 in. in diameter and 30 in. in length. Each port has an outer door hinged to wing out from port and an inner door hinged to swing into the cabin.

A. 1. 3 Safety Provisions Inside the SCS

The safety provisions of the SCS were completely reviewed for the 60-day test in accordance with References 5 and 13. The use of combustible materials was kept to a minimum. Paper products such as textbooks, technical data sheets, drawings and reports were stored in closed metal containers when not being used. Trash was placed in closed metal containers and was removed through the pass-through ports at least once each day. The test conductor, or his alternate, checked and approved every item that was passed into the SCS to prevent an excessive accumulation of combustible products. All fabric material used within the SCS for exposed clothing, curtains, bedding, and chair cushion covers was either Beta cloth or PBI material.

All electrical wiring insulation was made of teflon, or was encased within a teflon sheath or teflon tape. Proper bundling of electrical wiring was emphasized; i. e., alarm, power, instrumentation, and communication circuits were separated, and wiring bundles were supported at least every 24 in. with teflon-cushioned clamps. Ground and power wiring was sectionized on terminal boards and multiple pin connectors were used to minimize the possibility of shorting. Ground straps were provided between each piece of electric equipment and the SCS structure. All instrumentation leads connected to test crew members for monitoring physiological information were provided with extremely low amperage fuses to protect the crew member from shock in the event of a short circuit.

Other general safety provisions included safety glass installed under all overhead fluorescent light fixtures, a non-skid surface provided on the SCS floor, a dust and contamination control system provided during subsystem installation and test preparation, documented quality control provided on all items installed within the SCS, and detailed operating procedures and drawings of all inside subsystems provided for use by the [illegible] crew members. At least one inside crew member was required to be [illegible] all times; smoking was not permitted inside the SCS.

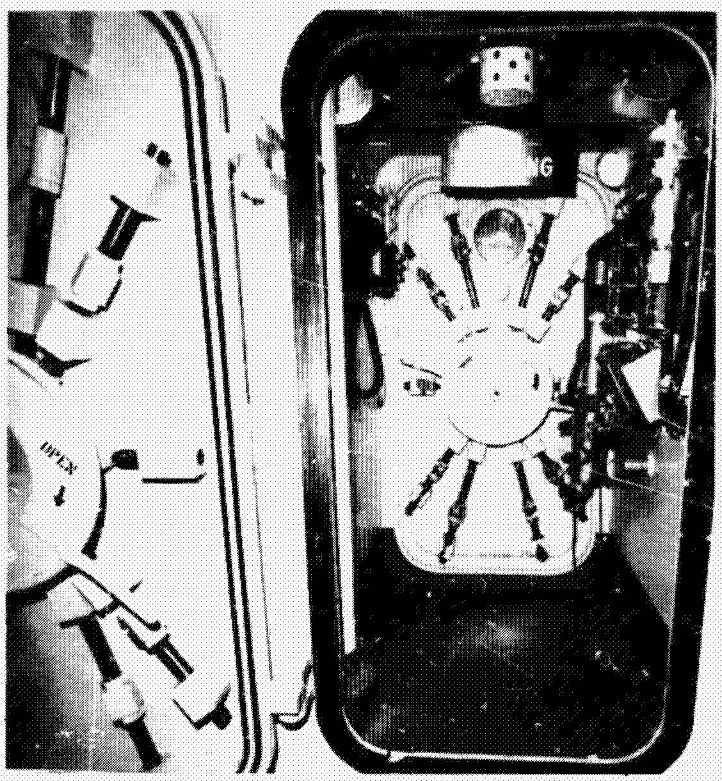


Figure A-3. SCS Airlock, Viewed from Outside the SCS

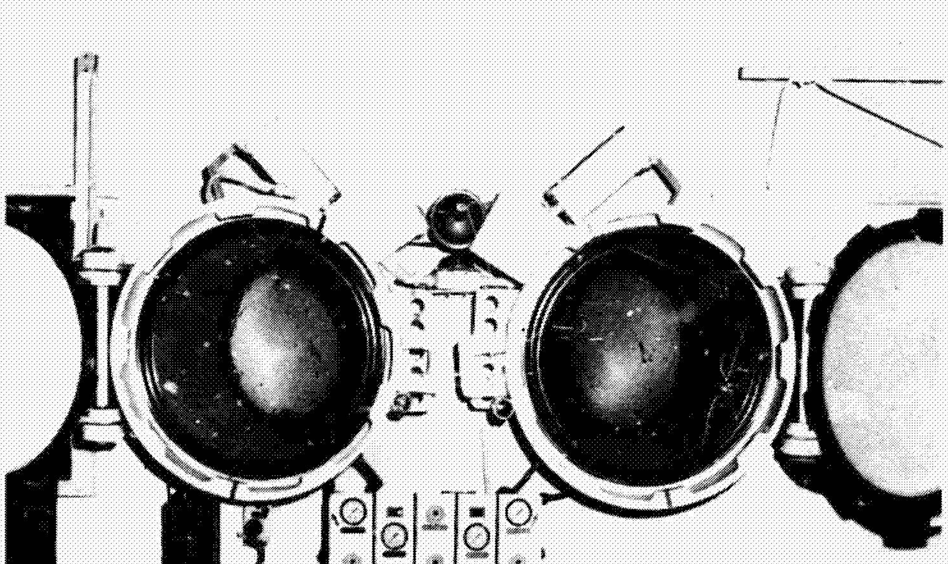


Figure A-4. SCS Pass-Through Ports and Controls, Viewed from Outside the SCS

Emergency systems and equipment were also included to increase safety provisions for the inside crewmen. These are outlined in Table A-1.

A. 1. 4 Life-Support Monitoring

The inside Life-Support Monitor (LSM) is located in the command area of the SCS, adjacent to the forward wall. The LSM is monitored by the crewman on command duty and is the central location within the SCS for determining the status of the cabin environment and specific SCS subsystems. The LSM contains a display of 10 meters, 56 status indicating lights, 13 selector switch lights, and 2 counters which provide immediate measurements of pressure, temperature, and gas concentrations and provide assurance of the safety status within the SCS. Figure A-5 shows the Life-Support Monitor inside the SCS.

Warning--Above the LSM is a warning display of six red lights which indicate, when illuminated, that smoke has been detected at the corresponding smoke-detector sensor locations. Three ionized gas sensors and three optical detectors were used to detect the presence of smoke at the following locations within the SCS:

Display Light Number	Sensor Locations
1	Equipment Cabinet
2	Air Evaporator Area
3	Waste Management Area
4	Aft Ceiling Area
5	Forward Ceiling Area
6	Command Area

Across the top of the LSM, there are 15 status indicator lights of which 7 are spares. Each of the remaining 8 indicates, when illuminated, that a critical life-support parameter has been detected to be out of the normal range of operation. The following parameters were monitored by this row of warning lights: Cabin air temperature, cabin pressure high, cabin pressure low, pO_2 low, pO_2 high, cabin carbon dioxide level, humidity, total hydrogen-carbon level, carbon monoxide level, and catalytic burner temperature.

Cabin Air Temperature--This portion of the LSM provides the capability to monitor cabin air temperature at the following six locations within the SCS:

1. Kitchen
2. Command Station
3. Exercise Area
4. Equipment Cabinet
5. Sleeping Quarters
6. Waste Management Area

These temperatures are monitored on a meter scaled from 50 to 100°F and are selected by depressing one of five momentary selector switch lights. The switch light pressed will become illuminated as the corresponding temperature

Table A-1

EMERGENCY SYSTEMS/EQUIPMENT
INSIDE THE SCS

Unit/Purpose	Description	Quantity/Location
1. Survivair Sac-Pac Air Packs/Provides protection from smoke inhalation.	The air packs contain a quick donning lightweight full face mask which can be donned without removing the air pack from its hanger. Each pack contains approximately 15 minutes air (30% O_2 and 70% N_2) supply and can be removed from the hanger and worn like a knapsack.	6 units/inside cabin at air pack stations.
2. M. S. A. Pocket Respirator/Provides an instant, convenient breathing apparatus to filter light concentrations of toxic gases or smoke and serves as an aid while getting to the air packs.	These are small, lightweight (0. 5 lb) breathing units with a cartridge filter. They are easy to don and are compatible with the intercom system. They do not lower the intake of O_2 percentage; however, the useful life of each filter is limited. The respirators serve as a secondary means of providing a breathable atmosphere up to a maximum contamination of 0. 1% by volume.	6/one in sleeping area, one in waste management area and one with each crew member as his personal equipment.
3. CO_2 Hand-Held Fire Extinguishers/Fire fighting.	Each unit contains 5 lb of CO_2, is portable, and is used temporarily for fire fighting.	4/in cabin next to the air pack stations.
4. Portable battery-powered light/Backup light in case of failure of emergency lighting system. May be used in troubleshooting and/or during repairs.	This portable light will be used by the crew if, during an abort procedure, the emergency lighting system fails. It may also be used temporarily for increased illumination in areas serviced by the regular and/or emergency lighting systems.	1/on the floor under the sink in the food management area.

Table A-1 (Continued)

Unit/Purpose	Description	Quantity/Location
5. Emergency intercom/ Backup for communications during cabin power failure or abort procedure.	This intercom channel of communication is available automatically upon loss of the primary 110-Vac power source; may be used any time.	1 channel/in cabin near the control console.
6. Emergency shower/ Temporary treatment of chemical burns, etc.	A 5-gallon overhead reservoir of water connected to a shower head. Shower can be activated by a pull handle.	1/in ceiling over the exercise area of the cabin.
7. Water spray nozzles/ Temporary crew protection from heat and flames in event of major fire.	Nozzles are supplied from the regular sprinkler system water supply for the building and are energized from the main control console by the Test Conductor. They operate during an emergency fire abort cabin repressurization and each will deliver 15 gallons per minute at 125-psi line pressure.	9/near the cabin ceiling, above the air pack stations, and along the central aisle of the cabin. (Seven are below the ceiling and two are above the ceiling.)
Two fire hoses/Fighting small fires.	These two stainless steel-braided, teflon-lined hoses are one inch in diameter and are isolated by a ball shut-off valve on one end and an industrial fog nozzle on the other end. The nozzles are adjustable with three flow positions and a shut-off. The hoses will deliver 28 gpm of water at a nominal pressure of 100 psig.	2 fire hoses/one near command-bunk area and one near waste management-exercise area.
8. Smoke detectors/ Immediate detection and notification of fire within the cabin in areas of application.	These smoke detectors are coupled with an inside/outside alarm system and are located near the water recovery system and in critical areas above the cabin ceiling.	Several/in areas near electrical equipment and potential fire hazards.

Table A-1 (Continued)

	Unit/Purpose	Description	Quantity/Location
9.	Toxic gas level system/ To detect dangerous levels of atmospheric contamination and immediately notify the crew and Test Conductor of the danger.	This system is in operation continually for detection of carbon dioxide, carbon monoxide, total hydrocarbons, oxygen, methane and hydrogen. Periodic analyses are also prepared for other trace contaminants.	1 system.
10.	Emergency lighting system/Backup system during power failure or abort procedures.	These battery-operated lights turn on automatically upon loss of the primary 110-Vac lighting circuit power. The four cabin lights are 6-Vdc, 25-watt sealed-beam lamps.	4 lights/in cabin ceiling panels over the main aisle.
11.	Cabin Emergency Dump Valve/Back-up valve for equalizing the cabin and ambient pressures.	A 4-inch, manually operated, sliding gate valve, requiring only 180° actuation of a lever to accomplish full open position.	1/in cabin exercise area, mounted on west side wall.
12.	Airlock Emergency Dump Valve/Back-up valve for equalizing airlock and ambient pressures.	A 2-inch, manually operated gate valve.	1/in airlock, mounted on west side wall.
13.	Airlock-Cabin Equalize Valve/Back-up valve for equalizing airlock and cabin pressures.	A 1-inch, manually operated gate valve.	2/one on east wall of airlock, one on west wall of waste management area.

Table A-1 (Continued)

	Unit/Purpose	Description	Quantity/Location
14.	ΔP Pressure gage/To visually monitor differential pressure between cabin and airlock.	The reading from this differential pressure gage provides an indication as to when the inner airlock door should be opened.	2/one mounted on the cabin side and one on the airlock side of the inner airlock door.
15.	Warning Siren and Bell/ To be used only to alert cabin crew members and all outside personnel that an emergency abort is being initiated immediately.	There are three safety-covered momentary toggle switches located within the simulator: one in the command center area; one in the food preparation area; and one in the exercise area. When actuated, these switches energize a 6-inch alarm bell and a siren. To silence the siren and alarm bell, a SIREN AND BELL button, located on the Test Conductor's main control console, must be depressed.	1 each/the warning siren is located outside of and above the cabin simulator and may be heard throughout the test area. The alarm bell is located inside the cabin on the aisle side of the sleeping area east wall and may be heard throughout the cabin.
16.	Emergency Oxygen System/To provide 100% breathing oxygen for inside crew use, with the cabin at altitude.	Four type A-14 diluters demand-pressure breathing oxygen regulators with attached pressure breathing oxygen masks supplied with 100% breathing oxygen at 450 to 500 psi from a bank of four O_2 cylinders and a reserve of eight O_2 cylinders.	4 sets/O_2 regulator and O_2 mask in the airlock.

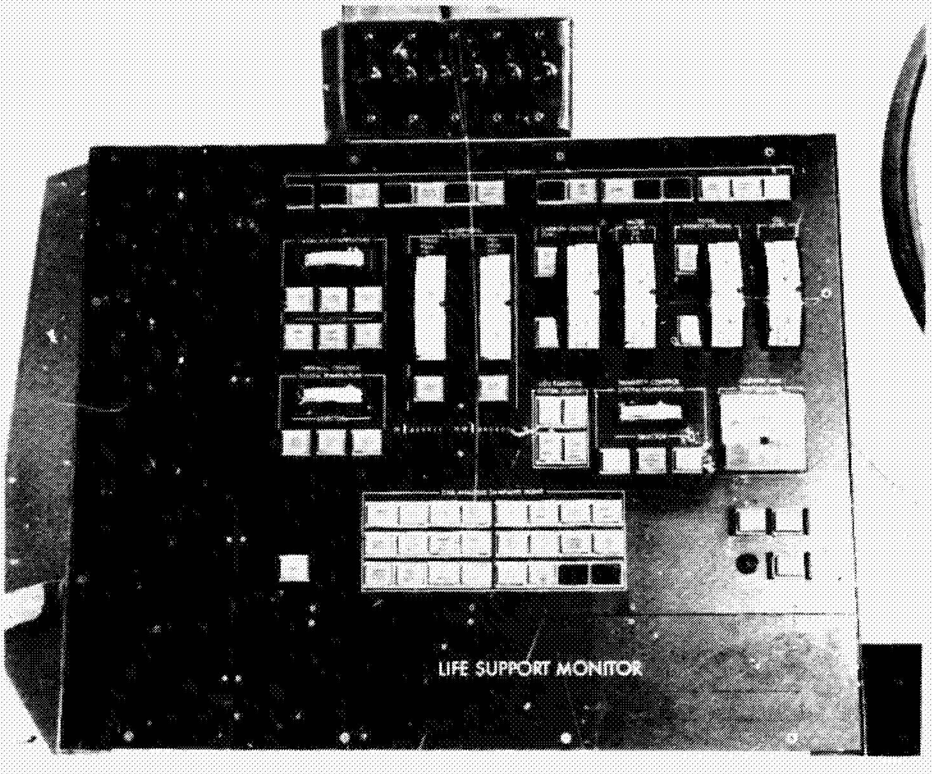


Figure A-5. Life Support Monitor Inside the SCS

is indicated on the meter. The command station temperature is indicated on the meter and the command station status indicator light is illuminated when no switches are pressed. A similar meter and light display repeats this data on the Life Support Monitor Console (LSMC) outside of the SCS.

Thermal Control Subsystem Temperature--This portion of the LSM provides the capability to monitor temperatures of air at the cooler outlet, and of Coolanol 35 at the cooler inlet and outlet, all within the thermal control subsystem. These temperatures are monitored on a meter indicating from 30 to 80°F. Either can be selected by pressing one of two momentary selector switch lights. The switch light pressed will illuminate as the corresponding temperature is indicated on the meter. The temperature of the air at the cooler utlet is indicated on the meter and the corresponding status indicator light is illuminated when no switches are pressed. This information is repeated by a meter and light display on the LSMC outside the SCS.

Atmospheric Supply--This portion of the LSM provides the capability of monitoring cabin total pressure, cabin partial pressure of oxygen, and a total count of the calibrated pulses of nitrogen and oxygen admitted to the cabin by the atmosphere supply control. The cabin total pressure in psia x 10 and the cabin $p0_2$ are monitored on meters scaled from 0 to 100 and 0 to 50-dc microamperes, respectively. Below these meters are two six-digit counters with reset capability and two status indicator lights. The left and right counters monitor the nitrogen and oxygen makeup pulses, respectively; the appropriate light illuminates momentarily in response to each pulse count.

Cabin Gas Concentrations--The following four portions of the cabin LSM provide the capability of monitoring the concentration level of carbon dioxide, water, total hydrocarbons, and carbon monoxide in the SCS atmosphere with the use of appropriate calibration curves. These meters repeat the readings indicated by four LIRA analyzers on the MSA Gas Analyzer Console outside of the SCS.

Carbon Dioxide Removal System Status--Four split indicator lights provide the capability of monitoring the operational status of the carbon dioxide concentrator. These four split indicator lights become and remain illuminated as the corresponding modes of the subsystem operation begin and continue. The various modes of operation include silica gel beds No. 1 and No. 2 adsorbing, molecular sieve beds No. 1 and No. 2 adsorbing, automatic and manual modes, and accumulator and space overboard desorption.

Humidity Control Subsystem Temperature -This section provides the capability to monitor air temperature at the condenser outlet, and Coolanol 35 temperature at the condenser inlet and outlet, all within the humidity control subsystem. These temperatures are monitored on a meter scaled from 30 to 80°F and are selected by pressing one of two momentary selector switch lights. The switch light pressed will illuminate as the corresponding temperature is indicated on the meter. The temperature of the air at the condenser outlet is indicated on the meter and the corresponding status indicator light is illuminated when no switches are pressed. A meter and light display on the LSM outside of the SCS repeats the indication of this section.

Catalyst Bed Temperature--The temperature of the catalytic bed in the toxin control subsystem can be monitored from a meter that continuously indicates temperatures on a scale marked from 0 to 1000°F and from 0 to 500°C.

Gas Analysis Sampling Point--This display includes 24 status indicator lights arranged in three rows. Each light represents one of the 24 MSA gas analyzer sampling points listed in Table A-2. This display enables the crewman on command station duty to determine which sampling point is the source of the gas sample being analyzed. The selection of the sampling point is made at the MSA Gas Analysis Console outside the SCS.

Lamp Test and Power Switches--There are two lamp test selector switch lights on the cabin LSM. These are momentary action switch lights and illuminate when pressed. When both of these lamp test lights are pressed, all the lights on the LSM will illuminate. This capability provides a check on the condition of the LSM lamps so that faulty or inoperative lamps may be replaced.

A. 2 SUPPORT FACILITY DESCRIPTION

This section describes the test equipment and facilities which were generally located near the SCS and were provided to support the 5-day and 60-day manned tests in the SCS, to simulate space environments, to monitor test conditions, to measure and record data, and to help meet the safety requirements of the manned SCS tests.

Table A-2

MSA GAS ANALYZER SAMPLING POINTS

Sampling Points	Location
1	Cabin Command Area
2	Cabin Equipment Cabinet
3	Cabin Bunk Area
4	Cabin Exercise Area
5	Cabin Waste Management Area
6	Air Evaporator Water Separator Gas Outlet
7	Air Evaporator Blower Outlet
8	Air Evaporator Charcoal Filter Outlet
9	Air Evaporator Charcoal Filter Inlet
10	Gas Flow to Adsorbing CO_2 Silica Gel Bed
11	CO_2 Heat Exchanger Inlet
12	Gas Discharge from Adsorbing Molecular Sieve Bed
13	Desorbing CO_2 Silica Gel Bed Condenser, Gas Discharge
14	Humidity Control Condenser Outlet
15	Humidity Control Blower Inlet
16	Thermal Control Heat Exchanger Gas Outlet
17	Thermal Control Blower Inlet
18	(Inactive)
19	Airlock
20	Cabin Kitchen Area
21	Toxin Control Particulate Filter Inlet
22	Toxin Control Economizer Inlet, Cabin Gas
23	Economizer Outlet, Reacted Gas
24	Toxin Control Particulate Filter Outlet

Sample points 6 through 24 are the 19 additional gas sampling points within the SCS.

A.2.1 Simulator Vacuum and Pressure Subsystem

The SCS is connected to a common vacuum manifold by two vacuum lines. One 8-inch line provides vacuum to the cabin and annulus through the main control console, and one 6-inch line provides vacuum to the airlock through the airlock control console. Figure A-6 is a schematic diagram of the SCS vacuum manifold and control valves.

Six vacuum pumps, one low-capacity and five high-capacity, are connected by manual valves to the common vacuum manifold. This provides for the selection of any particular pump or any combination of the pumps as required. Two auxiliary low-capacity pumps provide vacuum to the pass-through ports.

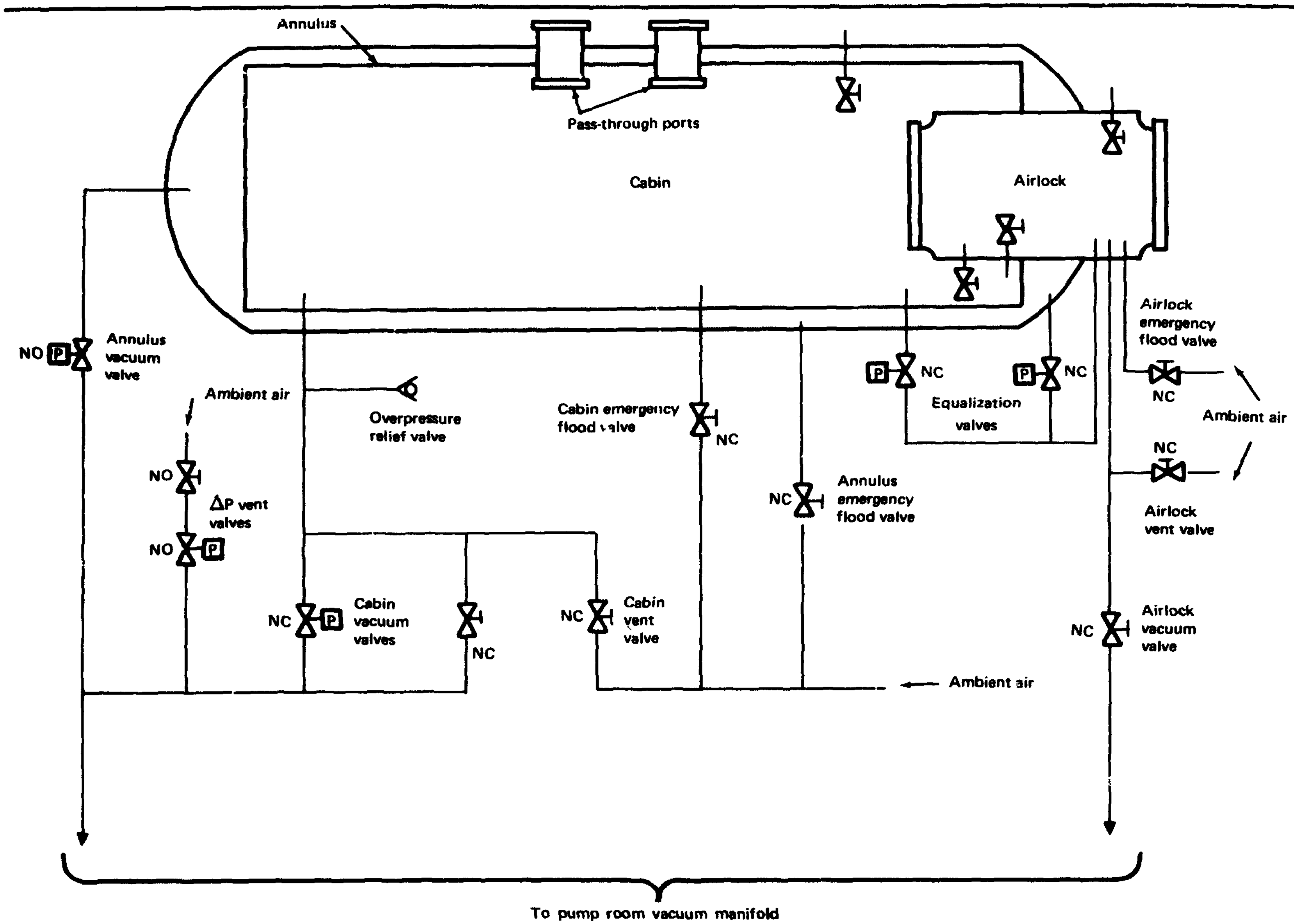


Figure A-6. Space Cabin Simulator Vacuum Control Schematic

Manual and electro-pneumatic valves and controllers are located at the main control console, interconnecting the 8-in. vacuum line, the two 6-in. vent lines, and lines from the cabin and annulus and provide the capability to select pressure, as desired. In a similar manner, manual valves are arranged at the airlock control console interconnecting a line from the airlock, the 6-in. vacuum line, and a 4-in. ambient vent line, making it possible to control the pressure in the airlock independently from the rest of the SCS. A 2-in. airlock-to-cabin line and valve, and a 2-in. airlock-to-annulus line and valve are operated from the main control console and permit equalizing of these pressures as desired. A second set of valves, located on the airlock control console, provide the capability of controlling the pressure between the door seals of the inner or outer door as required.

A.2.2 Thermal Conditioning Subsystem

The thermal conditioning subsystem includes the heating and cooling fluid facilities and the associated valves, switches, pumps, filters and indicators for Coolanol 35 fluid flow rates, temperatures, and pressures.

The cooling and heating requirements for the SCS life support and environmental control subsystems are fulfilled by two fluid conditioning and transport facilities. The cooling fluid facility provided Coolanol 35 at 34 to 40°F to the thermal and humidity control subsystems, the carbon dioxide concentrator, the potable and wash water recovery subsystems, and the Sabatier unit of the oxygen recovery subsystem. The fluid heating facility provides Coolanol 35 at 300 to 325°F to the carbon dioxide concentrator. Figure A-7 is a schematic of the thermal conditioning subsystem showing the interface between the cooling and heating fluid facilities and the SCS subsystems which use the cooling and heating fluids.

The cooling fluid facility is located outside the SCS and consists of a 90-gallon insulated storage tank, two Freon refrigeration systems to cool the Coolanol 35, each system with a circulation pump to force the Coolanol 35 through the evaporator coils and back to the storage tank; and an external plumbing system with two pumps in parallel, to supply the coolanol 35 to the SCS and return it to the storage tank. These parallel pumps provide redundancy to ensure high reliability. Shutoff valves are provided to permit independent operation of either pump. A regulating bypass valve controls the pressure of the delivered fluid.

The heating fluid facility is also located outside the SCS and includes a 45-gallon insulated storage tank, a 15-kW immersion heater within the tank to heat the Coolanol 35, a powerstat to control the voltage to the heater, a thermostat to control the temperature of the Coolanol 35 within the storage tank, a circulation pump, and plumbing to supply the fluid to the SCS, a vent and an overflow tank. Shutoff and bypass valves are located at the tank and at the pump to facilitate servicing and to regulate flow to the SCS.

A.2.3 Space Vacuum Simulation

The space vacuum subsystem provides for exhaust gases of the carbon dioxide concentrator, the waste management subsystem, and the Sabatier reactor.

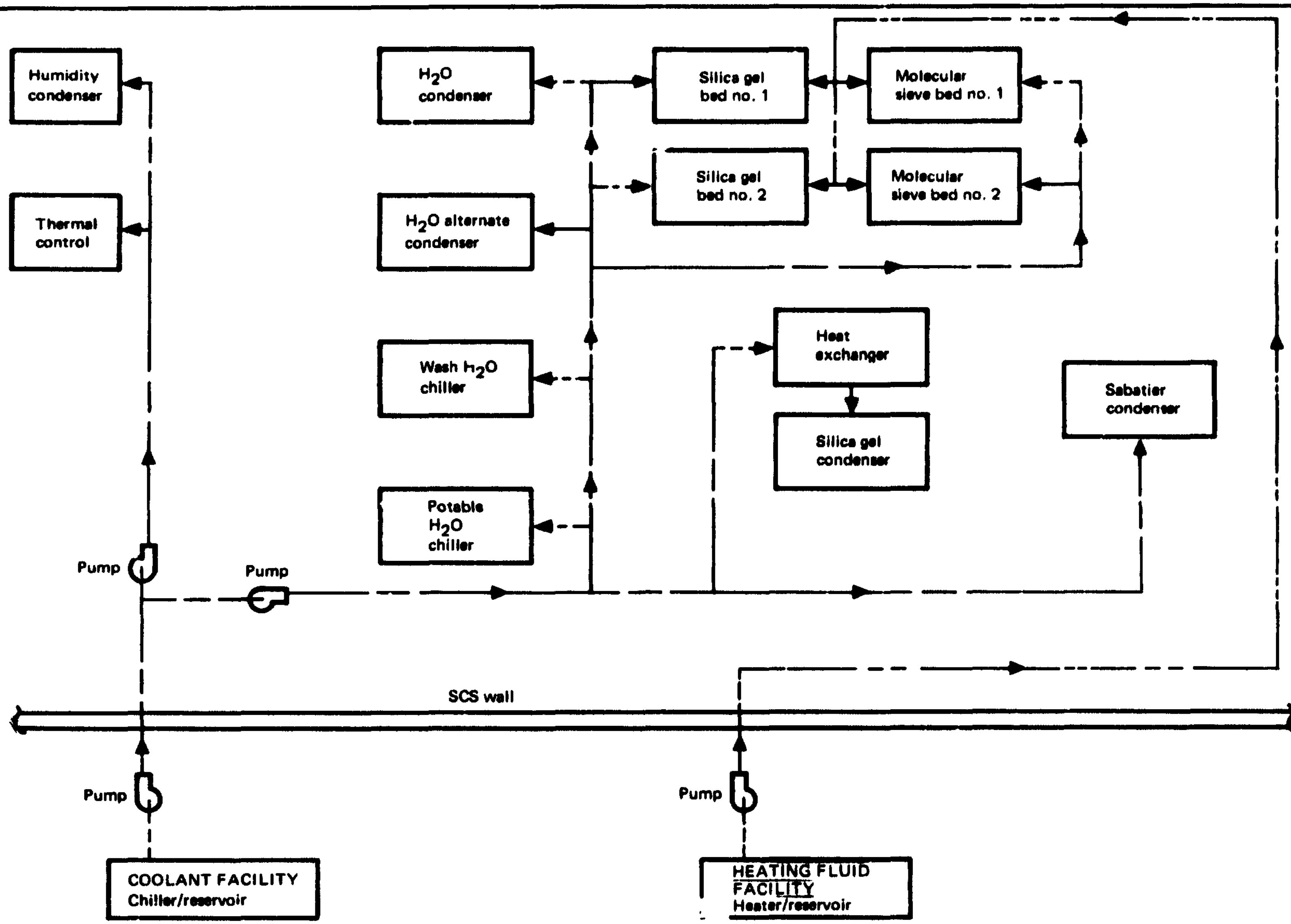


Figure A-7. Thermal Conditioning Subsystem

Two 15-cfm vacuum pumps operating in parallel are provided for the carbon dioxide concentrator and the waste management subsystem. These two vacuum pumps are located outside the SCS, and the necessary connecting lines, valves, and controls are provided to permit the use of either or both pumps on either or both subsystems. Figure A-8 is a schematic diagram of this portion of the space vacuum subsystem. Pressures attainable by these pumps are normally well under 1 mm Hg.

Two liquid-nitrogen cold traps are installed in the carbon dioxide concentrator space desorption line between the SCS and the vacuum pumps, and liquid nitrogen cold trap is installed in the waste management subsystem line leading to the two pumps. These three LN_2 cold traps are located outside the SCS and freeze the moisture and carbon dioxide from both locations as well as various other gases from the waste management subsystem. Provisions are made for these traps to be easily disconnected from the vacuum line and cleaned periodically. The two traps on the carbon dioxide concentrator desorption line permit cleaning of the traps one at a time without shutting down the subsystem.

Methane (CH_4), unreacted carbon dioxide and hydrogen, and trace gases produced in the Sabatier reactor are removed from the SCS by a 0.74-cfm vacuum pump located outside of the SCS. These gases are then vented through the roof of the building containing the SCS.

A.2.4 Electrical Power Subsystem

The electrical power required for operating the SCS subsystems and the support facilities includes the following:

1. 400-cycle, 120/208-V, three-phase.
2. 60-cycle, 440-V, three-phase.
3. 60-cycle, 115-V, single-phase.
4. 28-Vdc.

In addition, a backup power is provided by a 400-cycle standby motor-generator set and an emergency 28-Vdc battery-operated system. The battery system is normally under a regulated trickle charge but will automatically supply power if the primary 28-Vdc supply is terminated.

All incoming power is routed to the power distribution panel, located outside the SCS adjacent to the SCS main control console. At this distribution panel, the incoming power is distributed into separate circuits, each with individual current overload protection. There are nine 400-cycle, 120/208-V circuits, four 60-cycle, 440-V circuits, sixteen 60-cycle, 115-V circuits, and three 28-Vdc circuits. This distribution adequately fulfills the power requirements of the life support and environmental control subsystems listed in Table A-3.

A.2.5 Communications

Audio communication is provided by an Air Force-type AIC/10 intercommunication system. One power supply operates 12 intercom station units with 7 outside and 5 inside the SCS. Each intercom station unit accepts two headsets and provides a maximum of five channels. Oxygen masks for use

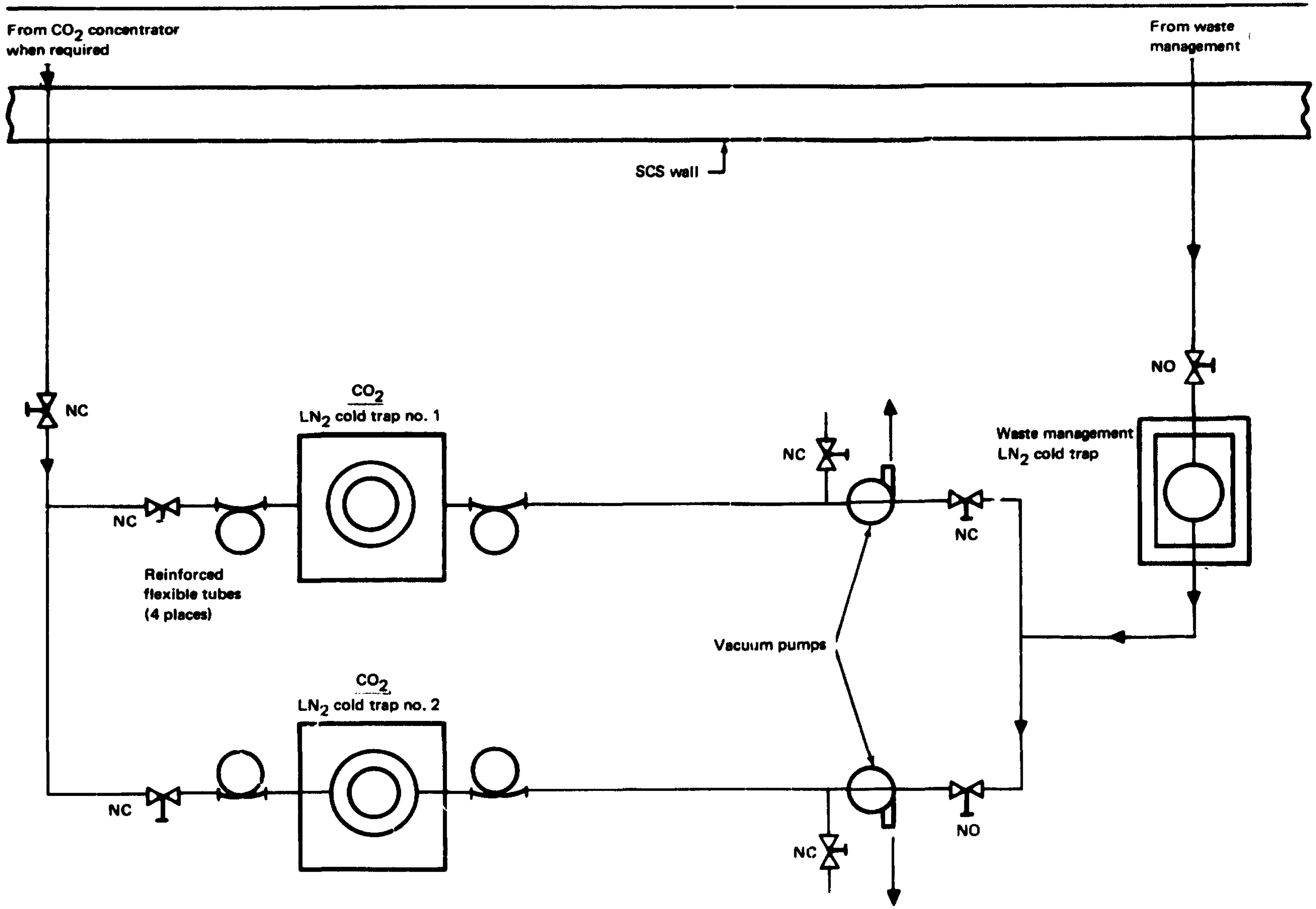


Figure A-8. Space Vacuum System for the CO_2 Concentrator and Waste Management Subsystems

Table A-3

SCS SUBSYSTEM POWER USAGE

(AVERAGE VALUES DURING TEST)

	Power Usage	Watts
1.	400 Cycle, 120/208 V, 3 Phase, 4 Wire:	
	O_2 Recovery Blower	90
	Water Recovery Blower	200
	Toxin Control Blower	300
	Thermal and Humidity Control Blowers	816*
	Waste Management Blower	100**
2.	60 Cycle, 440 V, 3 Phase, 4 Wire:	
	Thermal Conditioning Coolant Fluid Pumps	1495
	Thermal Conditioning Heating Fluid Pump and Heater	1151**
3.	60 Cycle, 115 V, 1 Phase, 3 Wire:	
	Water Recovery, Holding and Sterilizing Tanks and Heaters	1100
	Carbon Dioxide Concentrator Controller and Valves	750***
	Waste Management Slinger Motor and 4 Valves	48**
4.	28 Vdc, 2 Wire:	
	Toxin Control Heater	100
	Oxygen Recovery Startup Heater	200†

*Includes 56 W for auxiliary humidity control blower (not used during test).

**Intermittent operation at this level.

***Operates only minutes per day.

†Initial Startup and restart operations only.

within the airlock, and associated helmets, are also fitted with the AIC/10 communication system components. The location of the 12 intercom stations are shown in Figures A-1 and A-2.

The intercom channels are connected as follows to provide privacy for psychological testing and selected communications during an emergency:

1. Channel 1--All Stations.
2. Channel 2--All outside stations only.
3. Channel 3--Three desk stations outside and one station inside.
4. Channel 4--All stations.
5. Channel 5--All stations except Medical Room.

A call button is provided on each intercom station unit to attact the attention of the person to be called. When the button is depressed, an audible beep tone is generated and a visible yellow call light is illuminated at each of the station units.

In addition to the normal intercom system, an emergency, battery-operated system is provided with one headset and microphone located within the SCS Command Center Area and another headset and microphone located outside of the SCS at the test monitor's desk.

Visual communications can be maintained by a number of one-way view ports and a closed-circuit television system. Two of the closed-circuit TV units include a camera with a 10-mm lens in an explosion-proof housing, a remote pan-and-tilt unit, a camera cable, a remote control box, video cable, and a monitor unit outside the SCS. One of these two TV cameras is mounted in the SCS command area and the other in the food preparation/exercise area. The third TV unit consists of a portable camera with a 25-mm lens, a camera cable with the capability to reach anywhere within the cabin, selected remote controls, a video cable, and a monitor unit outside the SCS.

Ten one-way view ports provide direct means of observing the interior of the chamber. Seven of these view ports are in the side walls; one view port is in each of the two airlock doors, and one view port is located on the forward bulkhead. These view ports are shown in Figure A-1.

A. 2. 6 Data Collection and Instrumentation

Engineering data collection was accomplished automatically and manually during the 60-day manned test in the SCS. The recorded engineering data were reviewed daily during the test period. Critical performance parameters were monitored continuously to detect any impending failure or degradation of performance. The biomedical instrumentation and data collection equipment is described in Reference 1.

Engineering data were collected manually by the crewmen inside the SCS and by outside test personnel. In addition, data were collected automatically by two stripchart recorders and the Low Speed Digital System. The data collected automatically served to display transients within the systems and subsystems and the manually collected data provided a record of subsystem performance at frequent intervals throughout the 60-day period.

Data were collected manually from gages and meters inside and outside of the SCS and were recorded on subsystem data sheets. Data were manually recorded from instrumentation outside the SCS approximately once during each 8-hour shift and data from instrumentation inside the SCS were recorded manually on an average of twice during each 24-hour period.

Outside Test Data Collection, Manual--Once during each 8-hour shift, the SCS test monitors would manually record subsystem data from the Life Support Monitor Console, such as temperatures inside the cabin, water conductivity levels, Coolanol 35 flow rates, and gas mass flow rates. Other data recorded included percentages of cabin gas concentrations monitored from the Gas Analyzer Console, cabin pO_2 and total pressures, electrical power consumption for inside equipment, electrolyzer cell voltage and current, hot and cold Coolanol 35 reservoir temperatures, and methane vacuum-pump and orifice pressures.

During each 8-hour shift, the technician on duty would record data from various facility support systems. The data recording schedule included the following entries: every hour, the backup hot and cold water temperature and pressure and percentage concentrations of five cabin gases monitored on the Gas Analyzer Console; every 2 hours, the hot and cold Coolanol 35 and condenser water temperatures and pressures, the oxygen and nitrogen pulse counts at the Atmospheric Control Supply Console; every 4 hours, the oxygen and nitrogen manifold pressures, alarm light status, and emergency cylinder pressures, LN_2 trap refills, ice bath refills, nitrogen flow rate to the hot Coolanol 35 reservoir, the hot Coolanol 35 level and overflow, and the emergency nitrogen supply pressure; every 8 hours, the electrical power consumption of the inside equipment.

Outside Test Data Collection, Automatic--Two Leads and Northrop (L&N) stripchart recorders were used. One was used in the Life Support Monitor Console to record 16 important temperatures, and one was used in the Gas Analyzer Console to record gas concentrations of the atmosphere within the SCS. The multi-point L&N recorder, located in the MSA console, recorded carbon dioxide, carbon monoxide, water vapor, oxygen and hydrocarbons present in the SCS atmosphere.

To identify the data recorded throughout the test by the two L&N recorders, notes were made on the recording paper by test monitors. The notes included the reason for recording (routine, troubleshooting, special, etc.), the date (day, shift, and time), the operator's name or initials, and all significant events related to data being recorded.

Low Speed Digital System (LSDS)--The LSDS consists of a Systron-Donner Model 160E6 Data Acquisition Console as shown in Figure A-9. The LSDS is designed to receive data from 200 analog-input channels at a maximum scan rate of 200 channels/second. The LSDS scans, digitizes, and records on an IBM-compatible magnetic tape which may be later processed on a computer.

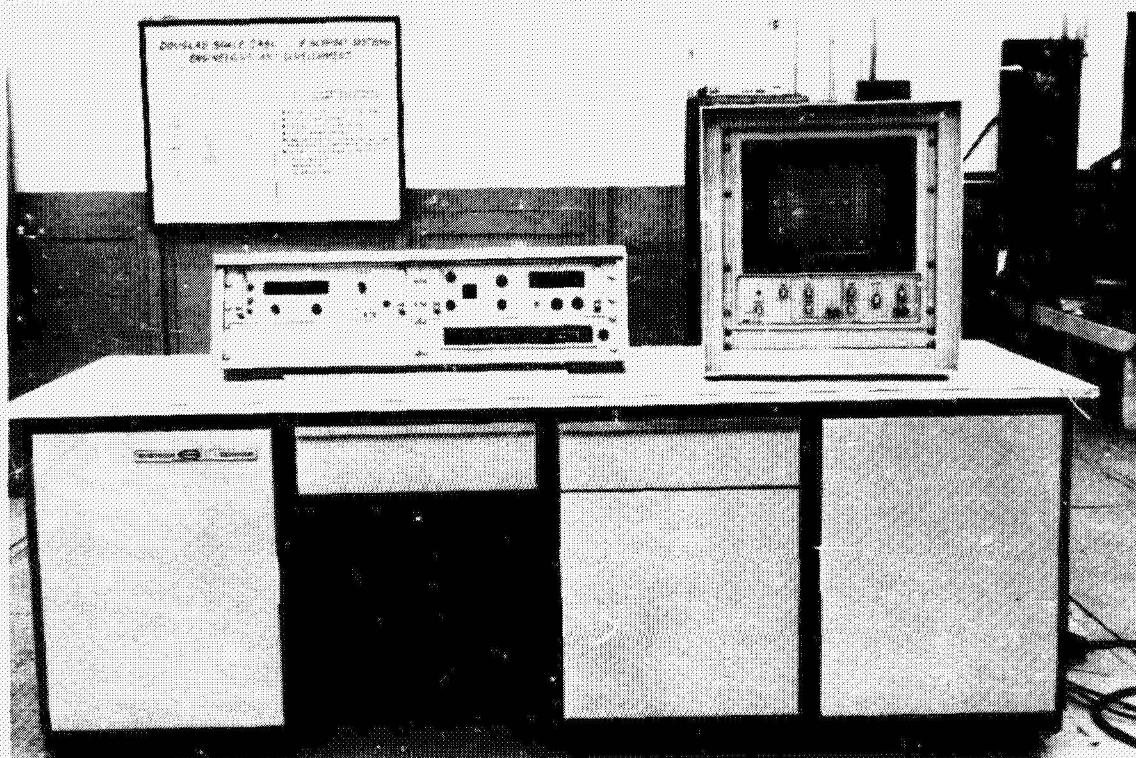


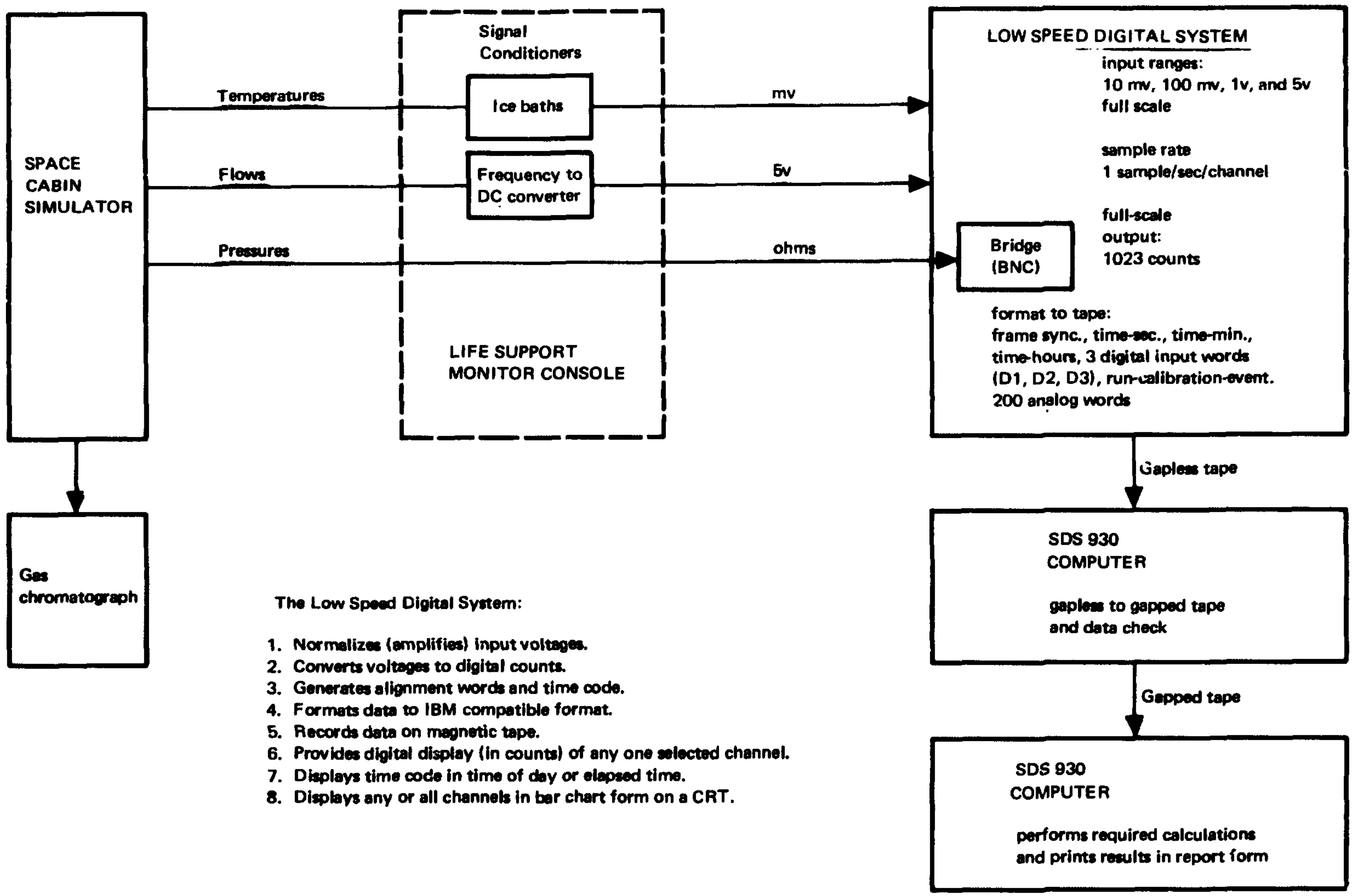
Figure A-9. Low Speed Digital System Console (LSDS)

A pinboard provides the means for setting the full-scale input range of each channel to be scanned. The ranges available are ±10 MV, ±100 MV, ±1 V, and ±5V. The pinboard also permits deletion from the scan of any unused or unwanted channel and the selection of the end channel in the scan.

The value of a particular analog input can be monitored during scanning by selecting the channel number on the monitor switches. When the particular channel is sampled, the value is indicated on the analog-to-digital converter readout display in four decimal digits plus the sign. This readout is stored and updated once each frame. A monitor oscilloscope displays all active channels within the selected group. The display of the selected channel within that group is accented in relation to the other channels.

A data flow diagram of the Low Speed Digital System is shown on Figure A-10. Electrical signals of the parameters measured in the SCS are conditioned in the Life Support Monitor Console which is located outside the cabin and adjacent to the LSDS. The numerical value of many of these parameters can be observed on the Life Support Monitor Console.

For the 60-day SCS test, the LSDS was used to record subsystem temperatures, pressures, and flow rates. It was intended at the start of the test to also collect gas sample data and dewpoint temperature data. However, it was not possible to collect this information because of the electrical noise with the data signals. The manufacturer of the LSDS was unable to correct this problem during the run; therefore, the gas sample and dewpoint temperature data were recorded manually.



The Low Speed Digital System:

1. Normalizes (amplifies) input voltages.
2. Converts voltages to digital counts.
3. Generates alignment words and time code.
4. Formats data to IBM compatible format.
5. Records data on magnetic tape.
6. Provides digital display (in counts) of any one selected channel.
7. Displays time code in time of day or elapsed time.
8. Displays any or all channels in bar chart form on a CRT.

Figure A-10. SCS/LSDS Engineering Data Flow Diagram

Table A-4 gives a detailed listing of the available instrumentation for each subsystem in the SCS and the engineering data monitored during the 60-day test. The table includes the subsystem and parameter monitored, the location of the sensor and the method of recording the data. The designations "I" or "O" under the Monitoring Location column indicate that the parametric values were monitored from the Inside or Outside of the SCS.

Life Support Monitoring System--The life support monitoring system consists primarily of a console made up of four cabinets (designated U1 through U4) which incorporate displays, meters and gages with a recording capability for some of the SCS subsystem data. Warning lights and/or audible alarms are used to monitor critical parameters of the subsystems involved with life support of the crewmen and control of their environment. The Life Support Monitor Console (LSMC) is shown in Figure A-11. The following paragraphs state the instrumentation and subsystem parameters located on the four cabinets.

Table A-4

SCS SUBSYSTEM DATA AND INSTRUMENTATION LOCATIONS

CARBON DIOXIDE CONCENTRATOR SUBSYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Temperature	Blower Outlet	X	X	O
	Silica Gel Bed Number 1 (3 places)	X	X	O
	Silica Gel Bed Number 1, Insulation Surface (2 places)	X	X	O
	Silica Gel Bed Number 1, Inlet	X	X	O
	Silica Gel Bed Number 1, Outlet	X	X	O
	Silica Gel Bed Number 2, (3 places)	X	X	O

Table A-4 (Continued)

	Silica Gel Bed Number 2, Insulation Surface (2 places)	X	X	O
	Silica Gel Bed Number 2, Inlet	X	X	O
	Silica Gel Bed Number 2, Outlet	X	X	O
	Heat Exchanger, Inlet	X	X	O
	Heat Exchanger, Outlet	X	X	O
	Molecular Sieve Bed Number 1 (3 places)	X	X	O
	Molecular Sieve Bed Number 1, Insulation Surface (2 places)	X	X	O
	Molecular Sieve Bed Number 1, Inlet	X	X	O
	Molecular Sieve Bed Number 1, Outlet	X	X	O
	Molecular Sieve Bed Number 2 (3 places)	X	X	O
	Molecular Sieve Bed Number 2, Inlet	X	X	O
	Molecular Sieve Bed Number 2, Insulation Surface (2 places)	X	X	O
	Molecular Sieve Bed Number 2, Outlet	X	X	O
	CO_2 Accumulator Number 1	X	X	O
	CO_2 Accumulator Number 2	X	X	O
	Desorbing Silica Gel Condenser, Inlet	X	X	O
	Desorbing Silica Gel Condenser, Outlet	X	X	O
Pressure	Blower Inlet		X	I
	Blower D. P.		X	I
	Silica Gel Bed Number 1 D. P.		X	I
	Silica Gel Bed Number 2 D. P.		X	I

Table A-4 (Continued)

	Desorbing Silica Gel Bed Condenser D. P.		X	I
	Heat Exchanger D. P.		X	I
	Molecular Sieve Number 1 D. P.		X	I
	Molecular Sieve Number 2 D. P.		X	I
	Molecular Sieve Desorption Vacuum	X	X	I, O
	Vacuum Pump Inlet		X	I
	Vacuum Pump Outlet		X	I
	CO_2 Accumulator Number 1	X	X	I
	CO_2 Accumulator Number 2	X	X	I
	Space Vacuum Line		X	I
	Accumulator Dump Line		X	I
	Space Vacuum Pump Inlet		X	I
	N_2 Supply		X	I
	CO_2 Backup Supply		X	I
	Sabatier CO_2 Supply, O_2 Partial		X	O
Flow	Silica Gel Bed Adsorption	X	X	I, O
	Silica Gel Bed Desorption		X	I
Power	Blower Motor		X	I
	Vacuum Pump Motor		X	O
Gas Sample	Silica Gel Bed Adsorption Flow, Inlet		X	O
	Heat Exchanger Inlet Flow		X	O
	Molecular Sieve Adsorption Flow, Exit		X	O

Table A-4 (Continued)

Gas Sample	CO_2 Accumulator Number 1		X	O
	CO_2 Accumulator Number 2		X	O
Dew Point	Adsorbing Silica Gel Bed, Outlet		X	O
	Desorbing Silica Gel Bed, Outlet		X	O
	Adsorbing Molecular Sieve, Outlet		X	O

THERMAL AND HUMIDITY CONTROL SYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Temperature	Thermal Control Blower Inlet	X	X	O
	Thermal Control Blower Outlet	X	X	O
	Thermal Control Heat Exchanger Outlet	X	X	I, O
	Humidity Control Blower Inlet	X	X	O
	Humidity Control Blower Outlet	X	X	O
	Humidity Control Condenser Outlet	X	X	O
	Cabin Atmosphere (6 places)		X	I, O
	Cabin Walls (16 places)	X	X	O
Pressure	Thermal Control Venturi D. P.	X	X	I
	Thermal Control Blower D. P.		X	I
	Thermal Control Heat Exchanger D. P.		X	I

Table A-4 (Continued)

	Humidity Control Venturi D. P.	X	X	I
	Humidity Control Blower D. P.		X	I
	Humidity Control Condenser D. P.		X	I
Gas Sample	Thermal Control Blower Inlet		X	O
	Thermal Control Heat Exchanger Outlet		X	O
	Humidity Control Blower Inlet		X	O
	Humidity Control Condenser Outlet		X	O
	Command Center Area		X	O
	Equipment Cabinet		X	O
	Bunk Area		X	O
	Exercise Area		X	O
	Waste Management Area		X	O
Power	Thermal Control Blower Motor		X	I
	Humidity Control Blower Motor		X	I
Dew Point	Air Evaporation System Area		X	O
Hydrogen Detection	Thermal Control Subsystem Inlet		X	O
	Sabatier Reactor Area		X	O
	Chamber Annulus		X	O
	Electrolyzer Area		X	O
	MSA Gas Sample Monitor		X	O

Table A-4 (Continued)

ATMOSPHERIC SUPPLY SUBSYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Pressure	Cabin Total	X	X	O
	Cabin O_2 Partial	X	X	I, O
	Cabin O_2 Supply		X	O
	Cabin N_2 Supply		X	O
Pressure	Electrolyzer O_2 Supply		X	O
	O_2 Bottle Supply, Regular		X	O
	O_2 Bottle Supply, Reserve		X	O
	O_2 Bottle Supply, Flow Meter Inlet		X	O
	N_2 Bottle Supply, Regular		X	O
	N_2 Bottle Supply, Reserve		X	O
	N_2 Bottle Supply, Flow Meter Inlet		X	O
Flow	O_2 Supply		X	O
	N_2 Supply		X	O

TOXIN CONTROL SUBSYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Temperature	Toxin Control Inlet	X	X	O
	Blower Inlet	X	X	O

Table A-4 (Continued)

	Blower Outlet	X	X	O
	Economizer Inlet	X	X	O
	Economizer Outlet	X	X	O
	Catalytic Bed and Heater Inlet	X	X	I
	Catalytic Bed Outlet	X	X	O
	Heater Inlet	X	X	O
Pressure	Blower D. P.		X	I
	Catalytic Bed D. P.		X	I
Power	Blower Motor		X	I
	Catalytic Bed Heater		X	I
Gas Sample	Toxin Control Inlet		X	O
	Toxin Control Outlet		X	O
	Economizer Inlet		X	O
	Economizer Outlet		X	O

THERMAL CONDITIONING SUBSYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Temperature	Coolant System Pump Outlet		X	O
	Coolant System Inlet to Cabin	X	X	O
	Coolant System Outlet from Cabin	X	X	O
	Thermal & Humidity Control Coolant Pump Outlet	X	X	O
	CO_2 Removal Coolant Pump Outlet	X	X	O

Table A-4 (Continued)

	Thermal Control Heat Exchanger Inlet	X	X	I, O
	Thermal Control Heat Exchanger Outlet	X	X	I, O
	Humidity Control Condenser Inlet	X	X	I, O
	Humidity Control Condenser Outlet	X	X	I, O
	H_2O Recovery Condenser In	X	X	O
	H_2O Recovery Condenser Outlet	X	X	O
	O_2 Recovery Condenser Inlet	X	X	O
	O_2 Recovery Condenser Outlet	X	X	O
	CO_2 Removal Heat Exchanger Inlet	X	X	O
	CO_2 Removal Heat Exchanger Outlet	X	X	O
	CO_2 Removal Condenser Inlet	X	X	O
	CO_2 Removal Condenser Outlet	X	X	O
Temperature	CO_2 Removal Silica Gel Bed Number 1 Inlet	X	X	O
	CO_2 Removal Silica Gel Bed Number 1 Outlet	X	X	O
	CO_2 Removal Silica Gel Bed Number 2 Inlet	X	X	O
	CO_2 Removal Silica Gel Bed Number 2 Outlet	X	X	O
	CO_2 Removal Molecular Sieve Number 1 Inlet	X	X	O
	CO_2 Removal Molecular Sieve Number 1 Outlet	X	X	O
	CO_2 Removal Molecular Sieve Number 2 Inlet	X	X	O
	CO_2 Removal Molecular Sieve Number 2 Outlet	X	X	O

Table A-4 (Continued)

	Heating System Inlet to Cabin	X	X	O
	Heating System Outlet from Cabin	X	X	O
	Heating System Reservoir		X	O
	Chiller H_2O Supply		X	O
Power	Coolant System Pump Motors		X	O
Flow	Thermal Control Heat Exchanger	X	X	O
	Humidity Control Condenser	X	X	O
	H_2O Recovery Condenser	X	X	O
	CO_2 Removal Silica Gel Beds Coolant	X	X	O
	CO_2 Removal Silica Gel Beds Heating Supply	X	X	O
	CO_2 Removal Heat Exchanger	X	X	O
	CO_2 Removal Molecular Sieves Coolant	X	X	O
	CO_2 Removal Molecular Sieves Heating Supply	X	X	O
	O_2 Recovery Condenser	X	X	O
	Potable & Wash Water H_2O Chillers		X	I
	N_2 Supply, Heating System Reservoir		X	O
Pressure	Reservoir Coolant Pump Outlet		X	O
	Booster Pump Outlets		X	I
	Thermal Control Heat Exchanger ΔP		X	I
	Humidity Control Condenser ΔP		X	I
	H_2O Recovery Condenser ΔP		X	I

Table A-4 (Continued)

	CO_2 Removal Silica Gel Bed Number 1 ΔP		X	I
	CO_2 Removal Silica Gel Bed Number 2 ΔP		X	I
	CO_2 Removal Heat Exchanger ΔP		X	I
	CO_2 Removal Condenser ΔP		X	I
	CO_2 Removal Molecular Sieve Number 1 ΔP		X	I
	CO_2 Removal Molecular Sieve Number 2 ΔP		X	I
	O_2 Recovery Condenser ΔP		X	I
	Heating System Pump Outlet		X	O
	Heating System Supply to Cabin		X	O
	Chiller H_2O Supply		X	O
	N_2 Supply, Heating System Reservoir		X	O

O_2 RECOVERY SUBSYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Temperature	CO_2 Orifice Inlet	X	X	O
	H_2 Orifice Inlet	X	X	O
	Sabatier Inlet	X	X	O
	Sabatier Catalyst Bed (3 places)	X	X	O
	Sabatier Bed, Insulation Surface (3 pieces)	X	X	O
	Sabatier Cooling Gas Inlet	X	X	O
	Sabatier Cooling Gas Outlet	X	X	O

Table A-4 (Continued)

	Sabatier Condenser Inlet	X	X	O
	Sabatier Condenser Outlet	X	X	O
	Sabatier CH_4 Orifice Inlet	X	X	O
	Sabatier Preheater Outlet	X	X	O
	Sabatier Temperature Controller		X	I
	Electrolyzer O_2 Purifier Outlet		X	O
	Electrolyzer O_2 Purifier ΔT		X	O
	Electrolyzer H_2 Purifier ΔT		X	O
Pressure	Sabatier H_2 Orifice Inlet	X	X	I
	Sabatier H_2 Supply		X	I
	Sabatier CO_2 Orifice Inlet	X	X	I
	Sabatier Supply ΔP		X	I
	Sabatier Inlet		X	I
	Sabatier Cooling Gas D. P.		X	I
	Sabatier CH_4 Orifice Inlet	X	X	O
	Sabatier CH_4 Orifice Outlet		X	O
	O_2 Storage Tank		X	O
	H_2 Storage Tank		X	O
	Sabatier N_2 Purge Supply		X	O
	Electrolyzer O_2 Purifier Outlet		X	O
	Electrolyzer H_2 Purifier Outlet		X	O
	Electrolyzer H_2O Seal O_2 Inlet		X	O
	Electrolyzer H_2O Seal O_2 Outlet		X	O
	Electrolyzer H_2O Seal O_2 D. P.		X	O

Table A-4 (Continued)

	Electrolyzer H_2O Seal H_2 Inlet		X	O
	Electrolyzer H_2O Seal H_2 Outlet		X	O
	Electrolyzer H_2O Seal H_2 D. P.		X	O
	H_2 Backup Bottle Supply		X	O
	N_2 Purge Supply		X	O
Flow	H_2O Pump		X	I
Power	H_2O Electrolysis Unit		X	O
	Sabatier Cooling Gas Blower		X	I
Gas Sample	Sabatier CH_4		X	O
	O_2 Storage Tank		X	O
	H_2 Storage Tank		X	O
	Electrolyzer Cell O_2		X	O
	Electrolyzer Cell H_2		X	O
	Electrolyzer O_2 Outlet		X	O
	Electrolyzer H_2 Outlet		X	O
Elapsed Time	Sabatier Cooling Gas, Solenoid Valve		X	I

H_2O RECOVERY SUBSYSTEM:

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Temperature	Air Evaporation Blower Inlet	X	X	O
	Air Evaporation Blower Outlet	X	X	O
	Air Evaporation Wick Inlet	X	X	O

Table A-4 (Continued)

	Air Evaporation Charcoal Filter Inlet	X	X	O
	Air Evaporation Charcoal Filter Outlet	X	X	O
	Air Evaporation Water Separator Inlet	X	X	O
	Air Evaporation Condenser Outlet	X	X	O
	Condensate Water Tank	X	X	O
	Potable Hot Water Tanks	X	X	O
	Wash H_2O Hot Water Tanks	X	X	O
Pressure	Air Evaporation Venturi D. P.	X	X	I
	Air Evaporation Venturi Inlet		X	I
	Air Evaporation Wick D. P.	X	X	I
	Air Evaporation Charcoal Filter D. P.		X	I
	Air Evaporation Condenser D. P.	X	X	I
	Air Evaporation Condensate Charcoal Column Number 1 Outlet		X	I
	Air Evaporation Condensate Charcoal Column Number 2 Outlet		X	I
	Air Evaporation Condensate Charcoal Column Number 3 Outlet		X	I
	Air Evaporation Condensate Resin Column Number 1 Outlet		X	I
	Air Evaporation Condensate Resin Column Number 2 Outlet		X	I
	Wash H_2O Filter F-B1 Inlet		X	I
	Wash H_2O Filter F-B2 Inlet		X	I

Table A-4 (Continued)

	Wash H_2O Filter F-B3 Inlet	X	I
	Wash H_2O Filter F-B4 Inlet	X	I
	Wash H_2O Filter F-B5 Inlet	X	I
	Wash H_2O Charcoal Filter CC-B1 Outlet	X	I
	Wash H_2O Charcoal Filter CC-B2 Outlet	X	I
	Wash H_2O Charcoal Filter CC-B3 Outlet	X	I
	Wash H_2O Resin Filter RC-B1 Outlet	X	I
	Wash H_2O Resin Filter RC-B2 Outlet	X	I
	Wash H_2O Recirculation Pump Outlet	X	I
	Air Evaporation System Charcoal Filter CC-B4 Outlet	X	I
	Air Evaporation System Charcoal Filter CC-B5 Outlet	X	I
	Air Evaporation System Charcoal Filter CC-B6 Outlet	X	I
	Air Evaporation System Resin Filter RC-B3 Outlet	X	I
	Air Evaporation System Resin Filter RC-B4 Outlet	X	I
Flow	Wash H_2O Filtration	X	I
	Condensate H_2O Filtration	X	I
Power	Air Evaporation Blower	X	I, O
	Air Evaporation Heaters	X	O
	Potable H_2O Tank Heaters	X	O
	Wash H_2O Tank Heaters	X	O
	Sink Pump	X	O

Table A-4 (Continued)

Gas Sample	Air Evaporation Blower Outlet		X	O
	Air Evaporation Charcoal Filter Inlet		X	O
	Air Evaporation Charcoal Filter Outlet		X	O
	Air Evaporation Condenser Outlet		X	O
Dew Point	Air Evaporation Blower Outlet		X	O
	Air Evaporation Charcoal Filter Inlet		X	O
	Air Evaporation Charcoal Filter Outlet		X	O
	Air Evaporation Condenser Outlet		X	O
Conductivity	CO_2 Removal System Condensate		X	O
	Air Evaporation System Condensation Tank		X	O
	Wash H_2O System Raw Tank		X	I
	Wash H_2O System Charcoal Filter CC-B1 Outlet		X	I
	Wash H_2O System Charcoal Filter CC-B2 Outlet		X	I
	Wash H_2O System Charcoal Filter CC-B3 Outlet		X	I
	Wash H_2O System Resin Filter RC-B1 Outlet		X	I
	Wash H_2O System Resin Filter RC-B2 Outlet		X	I
	Wash H_2O System Use Tank		X	I

WASTE MANAGEMENT SYSTEM

Parameter	Sensor Location	LSDS Data System (Automatic)	Visual Display (Manual)	Monitoring Location
Elapsed Time	Blower and Slinger Motors		X	I

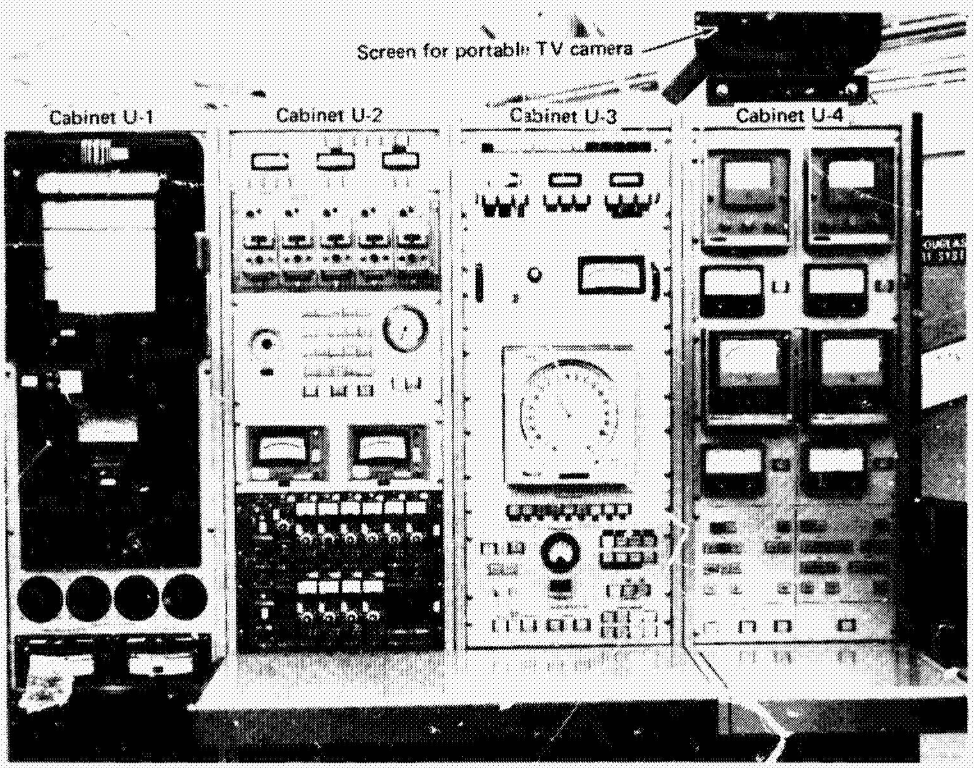


Figure A-11. Life Support Monitor Console, Outside the SCS—Cabinets U1, U2, U3, and U4

Cabinet U1 - - Cabinet U1 was used for monitoring the temperature of iron/constantan thermocouples at various locations in the cabin and mounted within the SCS subsystems. Cabinet U1 contains:

1. A Leeds and Northrop SPEEDOMAX stripchart temperature recorder with 16 channels used for measuring transient temperatures. Table A-5 contains the channel allocations for the temperature sensor measurements recorded on the stripchart recorder and a description of each of the sensor locations.

2. A Honeywell potentiometer with two ranges. This potentiometer was used to indicate values of 108 temperatures from thermocouples installed in the SCS. The large circular dial indicates temperatures within range 1 between -100°F and +500°F and within range 2 between 0. mV and 30 mV or +32° and ±1050°F.

3. Four temperature selecting Lewis switches, A, B, C, and D with 28, 28, 28, and 24 positions, respectively. These multipoint switches were used to remotely connect selected thermocouple circuits to the Honeywell potentiometer for indication of the selected temperature. These thermocouples are mounted inside the SCS at critical locations within the various subsystems and at locations on the command and the airlock bulkheads. These thermocouple readings provide a quick look for assessing the operation of the SCS life support and environmental control subsystems.

4. Two direct reading temperature gages which have a range of 0 to 400°F and read hot and cold Coolanol 35 temperatures at the inlet to the SCS.

Table A-5

TEMPERATURE RECORDER CHANNEL ALLOCATIONS

Channel Number	Sensor Location
1	Silica Gel Bed No. 1, Fluid Outlet
2	Silica Gel Bed No. 1, Gas Outlet
3	Silica Gel Bed No. 1, Bed Rear
4	Silica Gel Bed No. 2, Fluid Outlet
5	Silica Gel Bed No. 2, Gas Outlet
6	Silica Gel Bed No. 2, Bed Rear
7	Condenser Gas Inlet, Desorbing Silica Gel
8	Molecular Sieve No. 1, Fluid Outlet
9	Molecular Sieve No. 1, Gas Outlet
10	Molecular Sieve No. 1, Bed Rear
11	Molecular Sieve No. 2, Fluid Outlet
12	Molecular Sieve No. 2, Gas Outlet
13	Molecular Sieve No. 2, Bed Rear
14	Sabatier Reactor, Cooling Gas Outlet
15	Sabatier Catalyst Bed, Inlet
16	Sabatier Catalyst Bed, Middle

Cabinet U2. Cabinet U2 contains six panels which housed the following instrumentation:

1. Monitors for the Sabatier unit in the cabin and the water electrolysis unit outside the cabin.

   The following indicator lights for the Sabatier unit: HEATER, WATER PUMP, WATER SOLENOID OPEN, AIR SOLENOID OPEN, REACTOR VACUUM LINE, SENSOR ON LOW TEMP, REACTOR OVER TEMP.

   An API Controller Model 371-K displaying Sabatier reactor temperature. An under-temperature contact actuated the SENSOR ON LOW TEMP indicator light; an over-temperature contact actuated the REACTOR OVER TEMP indicator light, described above.

   The following indicator lights for the water electrolysis unit: O_2 HOLDER SWITCH FAILURE, H_2 HOLDER SWITCH FAILURE, CURRENT OVERLOAD, HI PRESS/O_2 ACCUM/LOW PRESS, HI PRESS/H_2 ACCUM/LOW PRESS, RESERVE HYDROGEN, SENSOR ON/H_2 PURITY, SENSOR ON/O_2 PURITY.

   Two API controllers, Model 371-K; H_2 Stream Contamination, and O_2 Stream Contamination. Each has over-temperature contacts and is operated by temperature differences across catalyst beds in the H_2 and O_2 streams at the outlet of the electrolysis unit. Over-temperature indications actuate the H_2 PURITY or O_2 PURITY indicator lights and alarms, respectively.

2. Five MSA Combustible Gas Analyzers and Alarm with Remote Sensors located:

   1. In the annulus exhaust to vacuum system.
   2. Under the building roof, over the water electrolysis unit.
   3. In the gas sampling line in the MSA Gas Analyzer Console.
   4. At the Sabatier cabinet purge gas exhaust.
   5. At the SCS thermal conditioning system blower inlet.

   These sensors indicate full-scale when the H_2 contamination reaches 1 percent. An audible alarm and red light are energized at a preset danger level.

3. The CO_2 concentrator status and alarm indicator lights. There are four rows of status indicator lights that display the immediate status of the CO_2 concentrator internal operations. Information is available on the overall mode of operation, the position of the vacuum and water pumps, the blower operation, the availability of power supplied to the subsystem, the CO_2 accumulator status, the heating and cooling times, and the adsorption-desorption status of the silica gel and molecular sieve bed was at any given time.

Five warning indicator lights on this CO_2 concentrator panel were used. The first three warning indicator lights monitored the air flow through the CO_2 concentrator at separate points and were actuated by differential pressure switches. Another dual indicator monitored CO_2 accumulator pressure, and a fifth indicator, actuated by a Beckman oxygen analyzer, indicated CO_2 purity. The CO_2 panel vacuum gage, a Wallace and Tiernan Model with a 2-3/4-inch dial and a range of 0 to 800-mm Hg, indicated the molecular sieve bed desorption pressure.

4. Two Linur mass flowmeters. The first one indicates the gas flow to the cabin from the adsorbing molecular sieve bed. The other mass flowmeter failed during the 5-day test and was not used during the 60-day test.

5. Ten Pottermeter frequency converters, two power suppliers, and one calibration unit. Potter meters are turbine-frequency type flowmeters which measured the flow of hot and cold Coolanol 35. Each converter had a percent-of-frequency scale meter and a calibration to 75 percent button. The frequency scale was selected by a switch located on each converter. The frequency was related to flow rate by a calibration curve for each unit. The frequency converters and meters were panel mounted, while the frequency counters and turbines were located in the corresponding lines of the SCS subsystems.

Cabinet U3. Cabinet U3 contains eight panels, with the following instrumentation:

1. The life support warning section with ten status and alarm indicator lights, each with an amber bulb. These ten warning and alarm lights were driven by alarm mechanisms from sensors within the SCS. An alarm silence switch light on the Warning Response Panel silenced the audible alarm which sounded when any alarm light was actuated.

   The warning indicator lights became illuminated after actuation of a switch or relay inside the SCS. These lights included warnings for serious variation in cabin temperature, total pressure, and humidity and for concentrations of CO, CO_2, O_2 and total hydrocarbons. One warning light monitored the temperature controller of the toxin control burner. Warning lights for the pO_2 were provided at the main control console outside the SCS and the MSA Gas Analyzer Console contained warning lights and a bell which operated in conjunction with the life support warning lights. All of these lights were duplicated on the LSM inside the SCS.

   The lower portion of this panel contained three temperature meters and their associated temperature indicator lights, all of which were controlled by selecting corresponding switch lights on the cabin LSM inside the SCS. When illuminated, each light indicated the location of the temperature sensor being used to provide the reading on the temperature meter. These locations included cabin air temperatures from the kitchen, bunk area, command area, equipment cabinet, the exercise area and the waste management area. The meter indicating these temperatures had a range from 50 to 100°F. Another meter, with a range of 30 to 80°F indicated the thermal control subsystem temperatures at the air cooler and coolant outlets and at the coolant inlet.

2. A Cambridge Systems, Model 992-T1, Dewpoint Hygrometer Readout Unit with three channels for dewpoint temperature ranges: -100 to +20°F, 0 to 120°F, and one for special applications. This dewpoint hygrometer readout unit was a part of the overall dewpoint measuring system and served to monitor the higher dewpoint temperature samples (0 to +120°F).

3. A Cambridge System Model 104 Electronic Indicator for dewpoint temperature with a range from -80 to +120°F. This unit was used specifically for the lower dewpoint temperature samples. This meter and the meter above were each driven by an input signal provided by a respective Cambridge Systems dewpoint analyzer located in the SCS waste management area. These analyzers were connected to various air sample locations within the SCS by a bank of solenoid valves. The solenoid valves opened the gas sample lines one at a time to allow samples to be pumped through the dewpoint cell. The samples returned either to the air evaporation system, or to the cabin, through a three-way solenoid valve.

4. The Dewpoint Sample Point Selector--a bank of nine interlocked switch lights. The first is an enable switch light and each of the remaining eight switch lights has a magnetic holding coil so that it stays on until a different switch is pressed. These eight switches activated the dewpoint air sampling solenoid valves in the waste management area of the SCS (as discussed previously) to select the proper sample location. The switches were interwired so that no more than one solenoid valve was open at one time.

5. Status and alarm indicator lights for the water recovery system: POWER/BLOWER/NO FLOW, HEATER, URINE LEVEL HIGH, CONDENSATE PUMP, URINE FEED PUMP, FEED TOTALIZER RESET.

   A counter indicating total urine feed in liters.

6. Master control indicator lights: 115 VAC POWER ON, 28VDC POWER ON, 110/220 400 CPS POWER ON.

   Lamp test switch for UNIT 2 and UNIT 3.

7. A WARNING RESPONSE panel with acknowledge and alarm silence capability for:

   1. ACKNOWLEDGE SABATIER
   2. ACKNOWLEDGE LIFE SUPPORT

3. ACKNOWLEDGE ELECTROLYZER H_2O RECLAIM

4. ACKNOWLEDGE CO_2 SYSTEM

When an alarm condition occurred in the SCS subsystems, the appropriate ACKNOWLEDGE switch lights illuminated, identifying the general area of the existing alarm condition. If the ACKNOWLEDGE switch light was not pressed within 6 seconds after lighting, an audible alarm sounded (bell or buzzer) indicating the subsystem requiring immediate attention.

Cabinet U4. Cabinet U4 housed instrumentation for the Suit Loop Monitor. This instrumentation was not used for the 60-day SCS test.

Gas Analyzer Console--A gas analyzer console (GAC) manufactured by the Mine Safety Applicances Company (MSA) is used to continuously monitor the inside cabin atmosphere. The GAC, shown in Figure A-12, contains four infrared analyzers, one paramagnetic (Beckman) oxygen analyzer and a Leeds and Northrop multipoint recorder which provided a continuous data printout for the five analyzers. Quantitative calibration of the analyzers was performed with appropriate span gases. The four infrared analyzers measure and indicate gas concentration percentages of carbon dioxide, carbon monoxide, total hydrocarbons and water vapor within the SCS. Table A-6 indicates the range of each analyzer and the printout location on the L&N multipoint recorder.

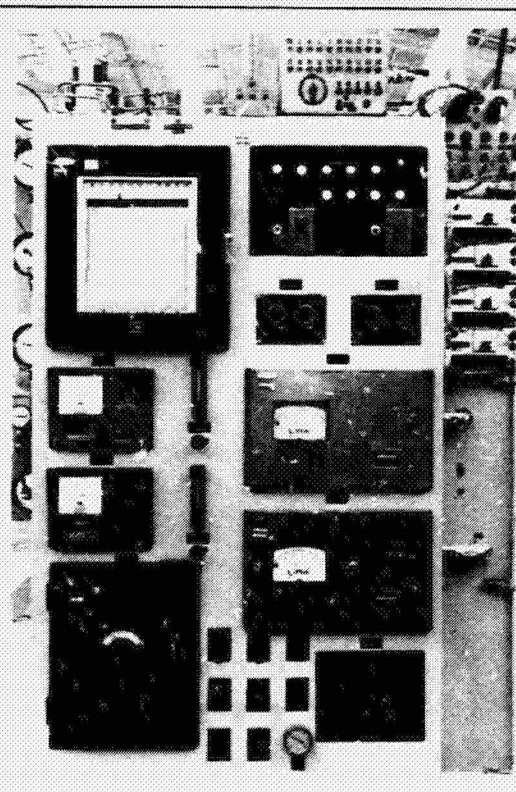


Figure A-12. MSA Gas Analyzer Console

Table A-6

MSA GAS ANALYZER CONSOLE INSTRUMENTATION RANGE

L&N Printout Number	Analyzer Monitor	Analyzer Range
1	Carbon Dioxide	0 to 1%; 0 to 5%
2	Total Hydrocarbons	0 to 122 ppm; 0 to 750 ppm
3	Carbon Monoxide	0 to 200 ppm
4	Water Vapor	0 to 3%
5	Oxygen	0 to 30%; 0 to 100%
6	Indicates which of the main sampling points is being analyzed	

Five main sampling points (Numbers 1 through 5) are provided for simultaneous and continuous analyses of the gas concentrations of the SCS atmosphere. An auxiliary sample line, No. 6, is designed to allow selection of one of 19 additional sampling points. By setting the GAC in the automatic mode, a sampling sequence selects the five main sampling points and one of the 19 auxiliary points in turn. The location of each of the 24 sampling points is listed in Table A-4.

A. 2. 7 Facility Safety Provisions

Safety provisions were planned and reviewed using analyses of recent accidents obtained from other facilities, and test data concerning burning rates of materials within oxygen-rich environments. The laboratory which housed the SCS was a restricted-access area during the test. Locks were installed on all access doors to the laboratory and were always secured to prevent entrance of unauthorized personnel. One door was provided with a doorbell and a remote electric lock release located at the test monitor's console. Visitors were permitted into the area only with proper authorization, were escorted by test personnel, and were required to register in a Visitor's Log.

Restricted smoking areas were established, posted, and enforced around the water electrolysis unit and other oxygen and hydrogen gas storage areas. Venting of oxygen, hydrogen and methane to the roof and outside the building was provided for the electrolyzer complex.

Ambul[illegible] entry doors were established with the parking approac[illegible] required, to prevent other vehicles and equipment fro[illegible] areas.

Skid-proof surfaces were provided on all platforms, catwalks and steps. An inclined ramp, extending from the airlock platform to the medical room doors, was provided to facilitate the transfer of injured crew members from the SCS if required.

All vacuum pumps used to pump the oxygen enriched SCS atmosphere were provided with synthetic, safe fluids such as Cellulube or Versilube for lubrication and sealing.

A facilities operating manual was provided with detailed operating instructions, general and emergency procedures, and schematics on all facility systems.

Other general safety provisions included flame retardant suits for personnel entering the SCS during the test run, if it became necessary for examination or inspection purposes, and a gas chromatograph to test gas samples from the SCS atmosphere and subsystem outlets.

Emergency systems and equipment were also provided as outlined in Table A-7.

A. 3 RELATED FACILITIES

The following section describes the related facilities available for the support of the 60-day manned test of the environmental control and life support system in the SCS.

A. 3. 1 Chemical Analysis Laboratory

The chemical analysis laboratory is located adjacent to the SCS test area. To support the manned 60-day test requirements for chemical analyses of the gas and particulate composition of the cabin atmosphere and the analyses of the reclaimed water from the water recovery systems, the following measurements were made by the personnel of the chemical analysis laboratory.

1. Organic trace contaminants in cabin atmosphere.
2. Chemical monitoring of carbon monoxide, carbon dioxide and hydrocarbons.
3. Wet chemical analyses for SO_2, (NO)x, NH_3, ozone, etc.
4. Analyses of reclaimed water.
5. Composition of exit gases from Sabatier hydrogenation unit.
6. Analyses of gases from hydrogen and oxygen storage tanks and CO_2 supply lines for contaminants.
7. Sorting and counting of aerosols inside the space cabin atmosphere over short time periods.
8. Measurement of total amounts of cabin aerosols over long time periods.

Table A-7

EMERGENCY SYSTEMS/EQUIPMENT RELATIVE TO THE FACILITY

Unit/Purpose	Description	Quantity/Location
1. Emergency power supply; 28 Vdc battery/Power source for emergency systems during power failure or abort procedures.	Standby battery powers the critical pressure control components in the event of a loss of the primary 28-Vdc power source. This battery is continually under a 28-Vdc trickle charge.	1 battery and charger/outside of and under the SCS
2. Emergency lighting system/Backup system during power failure.	Two separate systems:	
	1. Battery-operated 6-Vdc, 25-watt sealed-beam lamps automatically energized upon loss of primary 115-Vac building overload lighting. Batteries are being charged at all other times.	2/one each at the main control console and airlock control console.
	2. Diesel-operated motor-generator supplying 115 Vac to various locations throughout the entire McDonnell Douglas plant, one of which is an overhead fluorescent fixture in the Biotechnology Laboratory containing two 90-watt fluorescent tubes. The motor-generator starts automatically upon loss of primary power.	1/dual-tube fixture in the ceiling above the main control console.

Table A-7 (Continued)

Unit/Purpose	Description	Quantity/Location
3. Emergency intercom/Backup for communications during cabin power failure or abort procedure.	This intercom channel of communication is available automatically upon loss of the primary 110-Vac power source.	1 channel/one headset is in the cabin near the control console, the headset outside the SCS is adjacent to the TV monitoring station.
4. Cabin ambient repressurization valve/To rapidly repressurize the cabin to sea level.	This is a manually operated 6-inch sliding gate valve (CABIN EMERGENCY FLOOD) which directly connects the cabin to ambient pressure, requiring only 180° of lever actuation to place at full open position.	1/at Test Conductor's main control console.
5. Airlock ambient repressurization valve/To rapidly repressurize the airlock to sea level.	A 4-inch manually operated gate valve (EMERGENCY FLOOD) directly connects the airlock to ambient pressure, requiring only 90° of lever actuation to place at the full open position.	1/at Test Monitor's airlock control console.
6. Airlock Equalization Valves/ 1. To rapidly close off the airlock from the cabin pressure, 2. To rapidly equalize the airlock with the cabin pressure.	Two electro-pneumatic actuated 2-inch sliding gate valves operated by two toggle switches. (LOCK TO ANNULUS EQUALIZATION) and (LOCK TO CABIN EQUALIZATION)	2/actuated at the Test Conductor's main control console.

Table A-7 (Continued)

Unit/Purpose	Description	Quantity/Location
7. Nitrogen repressurization system/To rapidly repressurize the cabin to sea level and to serve as a fire suppressant.	High-pressure gaseous N_2 system automatically supplies a stream of inert gas into the most likely areas for fires and thereby reduces the local oxygen concentration and creates an inert gas blanket. When used with the 6-inch manual cabin flood valve, the cabin can be repressurized from 7 psia to 14.7 psia within 35 seconds.	1/actuated from the Test Conductor's main control console.
8. Cabin swing check valve/To immediately relieve the cabin over pressure.	This relief valve will help to protect the crew members from any sudden overpressure condition.	1/on cabin vent line.
9. Warning Siren and Bell/To be used only to alert cabin crew members and all outside personnel of an emergency abort situation.	In addition to the three actuation switches located inside the SCS, this alarm may also be actuated by a safety-covered momentary toggle switch located on the Test Conductor's main control console adjacent to the emergency abort switch and cabin flood valve. When actuated, this switch energizes a 6-inch alarm bell and a siren. To silence the siren and alarm bell, a SIREN AND BELL button, located on the Test Conductor's main control console, must be depressed.	1 each/the warning siren is located outside of and above the cabin simulator and may be heard throughout the test area. The alarm bell is located inside the cabin on the aisle side of the sleeping area east wall and may be heard thoughout the cabin.

Table A-7 (Continued)

Unit/Purpose	Description	Quantity/Location
10. Inside power emergency shut-off switch/Terminates all electrical sources to the SCS.	Switch actuation will terminate all electrical power to the cabin interior, except power for the intercom and the television cameras. It will also terminate electrical power to the hot and cold Coolanol 35 pumps located outside the SCS.	1/at Test Conductor's main control console.
11. Emergency abort switch/Initiate emergency abort procedures with various cabin simulator systems.	Lifting the lever guard and placing this emergency abort toggle switch to the ON position accomplishes the following: 1. All inside power, except to the intercom and television cameras, is shut off. 2. The inside, battery-operated emergency lights are turned on. 3. Power to the outside Coolanol 35 pumps is shut off, also the valves in each pump outlet/SCS supply line are closed. 4. The emergency GN_2 system is actuated. 5. The water spray system is actuated. 6. The Lock-Annulus Equaliza-	1/on the Test Conductor's main control console adjacent to the CABIN EMERGENCY FLOOD valve handle.

Table A-7 (Continued)

Unit/Purpose	Description	Quantity/Location
	7. The Lock-Cabin Equalization valve is opened. 8. The hydrogen supply line from the atmospheric supply system is shut off.	
12. Hot Line emergency telephone/To obtain immediate support from the Douglas Fire Department and Dispensary.	The phone is connected to the Main Police Desk and when removed from hook, an immediate alert is established at the Douglas Fire Department and Dispensary. Fire trucks and an ambulance crew are dispatched without a conversation being necessary.	1/at the Test Conductor's main control console above the Cabin Emergency Flood valve and the Emergency Abort Switch. The telephone is placed within a red box with a door that is spring loaded closed to prevent accidental initiation of an alert.
13. Fire and smoke protective equipment/Fire and smoke protection for the rescue crew during a fire abort procedure.	Coats, hats, boots, gloves, fabricated with Gentex (rayon/mylar); air packs, consisting of a full face mask and an approximate 15 minute supply of bottled air; all of which may be donned quickly.	2 sets/at the outer airlock door, outside the SCS
14. CO_2 supply/Fire fighting.	CO_2 nozzle connected to a 100 lb CO_2 supply by means of a 50-foot hose on a reel.	1/at the outer airlock door, outside the SCS.

Table A-7 (Continued)

Unit/Purpose	Description	Quantity/Location
15. Emergency medical treatment facilities/For medical treatment in the immediate area of injured or incapacitated crew members.	The emergency medical facility included a 4-bed clinic in the immediate vicinity equipped with an internal/external defibrillator, a heartpacer, an EKG machine, therapeutic O_2, a manual resuscitator, and resuscitative drugs. Available nearby is the McDonnell-Douglas Dispensary with an ambulance.	2/one in the immediate area of the Space Cabin Simulator. One within a 5-minute load-to-unload time from the SCS.
16. Hyperbaric chamber/For treatment of altitude dysbarism.	This chamber will be used to treat a crew member who has incurred altitude dysbarism.	1/near outer airlock in the cabin simulator area.

Instrumentation and analytical methods used to carry out these measurements consisted of:

1. Two Perkin-Elmer Model 800 gas chromatographs equipped with dual columns, and a Perkin-Elmer Model 810 flame ionization detector. The columns were packed with two different substrates and were operated at two temperatures. This made it possible to identify and quantitate trace contaminants at concentrations of less than 1 ppm.

2. A Perkin-Elmer Model 521 grating infrared spectrophotometer and one MAT Model CH4 mass spectrometer were used for definitive identification of unassigned gas chromatographic peaks. Gas samples were concentrated by freeze-out at liquid nitrogen temperature whenever larger gas volumes were required.

3. Daily cabin atmosphere samples were analyzed for ammonia, sulfur dioxide and other inorganic contaminants by conventional wet chemical methods. A Coleman Model 6A spectrophotometer with a Model 6-054 power supply was used to measure color intensities which were compared with calibrated concentration curves.

4. Water samples from different locations within the water reclamation system were analyzed for COD, conductivity, ammonia and chromium. Calibrations were performed and procedures were standardized. Test results obtained in this facility were provided to the test medical director as a basis for his decision of the water potability. Instruments used for these analyses included pH meters, conductivity meters Liebig condensers, and distillation flasks for refluxing purposes.

5. A Perkin-Elmer Model 154D vapor fractometer, with a thermal conductivity detector, was calibrated to measure incoming gases and reaction products of the Sabatier reactor. Gas analyses were made for methane, hydrogen, carbon dioxide, oxygen and nitrogen. These data were helpful in establishing a material balance of the reactants entering and leaving the Sabatier reactor. Oxygen and hydrogen supplies produced by the electrolysis unit were checked for impurities. Carbon dioxide lines leading from the molecular sieve beds to the Sabatier reactor were also tested for the presence of contaminants.

6. Procedures for the replacement of the battery in the aerosol particle analyzer sampler, the recharging of the battery in the aerosol sampler, and the use of these two aerosol samplers supplied by NASA/ERC were directed by the personnel of the chemical analysis laboratory.

A. 3. 2 Microbiology Laboratory

The Microbiology Laboratory was used to support the 60-day manned test of the SCS in the following areas:

1. Reynier and Anderson samplers and settling plates were used to obtain quantitative counts of the airborne microbial levels present.

2. Microbial samples were taken from various sites on the test subjects.

3. Processing of blood samples.

4. Microbial monitoring of the potable water reclamation system.

5. Microbial monitoring of the wash water multifiltration system.

6. Packaging, washing and sterilizing microbial filters and resin and charcoal columns for use in the potable water and wash water recovery subsystems.

To perform the required analyses of the various samples, all of the major facilities and capabilities of the Microbiology Laboratory were used. Included were the equipment and supplies necessary to perform clinical laboratory procedures in hematology, urinalysis, and clinical chemistry. Specific procedures included the use of an aerobic incubator, a walk-in incubator, water baths, air samplers, pH meters, conductivity bridges, centrifuges, an autoclave, automatic pipetting equipment, and microscopic equipment by two full-time microbiologists, a technician and a laboratory aid. Details of the results of microbial monitoring are provided in Reference 1.

A. 3. 3 Data Processing

A new automatic data system was utilized to record engineering data during the 60-day test. Temperatures, flow rates, and pressures which originated as analog signals from subsystem instrumentation were converted to digital form and recorded on magnetic tape by the Systron-Donner Low Speed Digital System (LSDS) at a scan rate of 200 channels per second.

Magnetic tapes produced by the LSDS could be processed on any pre-programmed moderate or large capacity digital computer. An SDS 930 digital computer was used for this task during the 60-day test. It was programmed to accept the digitized words from the LSDS magnetic tape and apply a specific calibration and/or conversion value to each channel recorded. The reduced engineering data were printed in tabular form with each subsystem record separated for a particular scan time.

In addition to the tabular output furnished by the SDS 930 computer, a plotting routine was available for any channel by use of a CAL COMP 570 machine. The CAL COMP 570 used the SDS 930 output tape to plot the parameter as a function of scan time. This capability was utilized to give the transient temperature profiles of the adsorption beds of CO_2 concentrator subsystem during cyclic operation.

Further manipulation or processing could have been done on the UNIVAC 1108 Data Processing System. This system features a control unit composed of integrated circuits with a cycle time of 125 nanoseconds. The associated magnetic core storage ranges from 32, 678 to 131, 072 words. Operation of the system is controlled by a program of instructions stored in the central processor. The system's core storage is supplied in modules of 16, 384 words of 36 bits each, with a minimum configuration of 32, 678 words and a maximum configuration of 131, 072 words. The central storage is organized into two to four modules, with each module having either 16, 384 or 32, 760 ords. Cycle time is 750 nanoseconds and overlapping operation provides an effective cycle time of 375 nanoseconds. There are 128 integrated circuits in this system. The 16 input-output channels are equipped with an externally specified index for multiplexing and on-line control of many communication and transmission devices. Concurrent words are multiplexed to provide a maximum communication rate of 8, 009, 000 characters per second. Most engineering computations are done on this equipment at present.

Physiological data recording was possible in analog form on a 14-channel magnetic tape recorder included in the Physiological Display System (see Reference 1). This tape record could be retained for permanent record and displayed as desired by the four-channel Sanborn CRT or permanent chart records could be made on a multiple channel Visicorder.